Semiconductor Devices

EB-6103-71 LAB BOOK 595-4897-03

Core Technology

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Semiconductors Devices, Lab Book

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Introduction

The EB-6103-71 Laboratory Workbook is to be used in conjunction with the ETB-6103 circuit board package. These products are designed to be used with the ETW-3600 Analog Trainer and the ETW-3567 Backpack Accessory. The Laboratory Workbook accompanies, supports, and augments the material contained in the Semiconductor Devices Textbook. The experiments in this workbook provide you with practical, hands-on experience to reinforce your understanding of material contained in the textbook. In addition, this workbook contains practice examinations covering each unit (1-10) in the textbook.

The ETB-6103 package contains three circuit boards of experiments plus several parts needed for the experiments. The extra parts are contained in a storage tray that stores on top of the circuit boards in the carrying case.

Each circuit board has two sections. The upper section contains a number of blocks where you will perform the experiments. Each block is dedicated to an experiment or to part of an experiment. The lower section contains the Circuit Board Interface Panel. Using the terminals on this Panel, you'll connect the experiments to the Trainer's outputs and potentiometers. Available at the Interface Panel are the Trainer's positive (+), negative (–), +5-volt, and ground (GND) power supply outputs, sine wave output, and the 1 kilohm (kΩ) and 100 kilohm (kΩ) potentiometers. Also on the Panel is a power switch that disconnects DC voltages from the Panel voltage terminals. An LED indicator lights when the power switch is turned on.

Circuit Board #1 also contains a special converter circuit to be used with the Trainer's built-in multimeter. It is used in several experiments involving the testing of semiconductor devices. Some ohmmeters (like the one used in the ETW-3567 Backpack) use a test voltage that is lower than the barrier voltage of a diode. Therefore, these ohmmeters cannot measure junction resistances. The converter circuit is included with Board #1 to enable the Backpack's meter to make these measurements. The circuit produces a voltage in proportion to the resistance placed across its input. This voltage is then measured by the Trainer's multimeter. You read the value of the resistance directly from the meter's display.

As we've mentioned, the three circuit boards are divided into blocks of experiments. Each block contains a circuit consisting of components, like resistors, capacitors, and so on, as you would see on any circuit board. Some blocks require you to connect a jumper wire or wires to complete a circuit for an experiment. The jumper connection will be called out in the steps for the experiment.

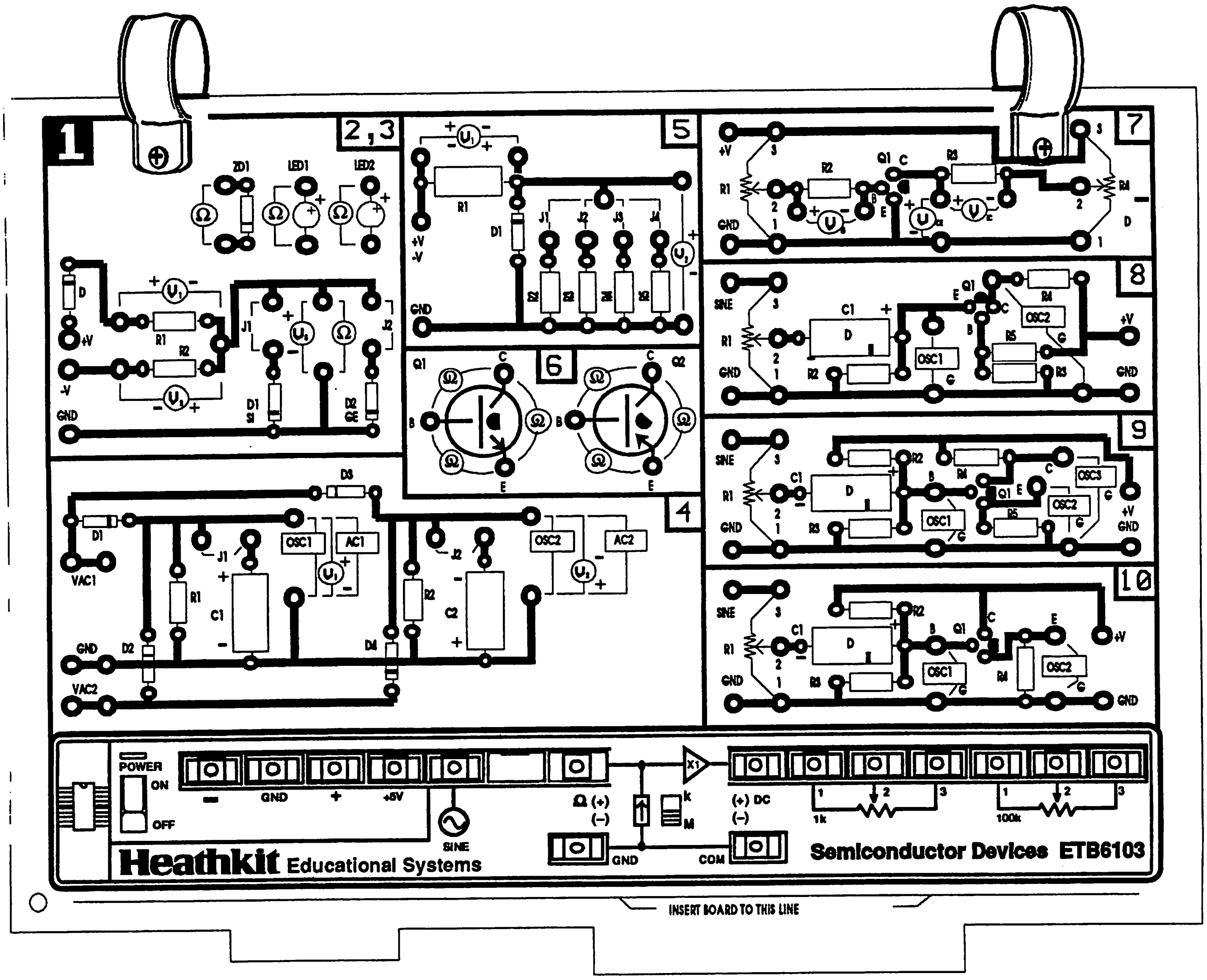
The circuit boards plus backpack significantly reduces the number of individual parts needed to set up an experiment, which provides more time for learning. In addition, the built-in multimeter of the ETW-3567 Backpack Accessory provides each work station with a handy and accurate means to measure voltage, current, and resistance.

The experiments contained in this workbook cover the most important concepts presented in the textbook. Beginning with Experiment 1, you will learn about the proper operation and use of your laboratory equipment. In Experiments 2 and 3 you will investigate the characteristics of typical diodes and how to test them. Next, in Experiments 4 and 5, you will examine diode rectifiers and zener diodes. In Experiments 6 through 10, you will learn about PNP and NPN transistors. Then you will observe and measure the electrical characteristics of an NPN transistor used in common-emitter, base, and collector amplifier configurations. Experiment 11 examines an NPN amplifier. Experiments 12 through 15 examines the characteristics of the JFET, SCR, and UJT. Experiments 16 and 17 introduce you to digital ICs and their operation. Experiments 18 and 19 demonstrate the characteristics of light sensitive and light emitting semiconductor devices. In the final experiment, you'll combine diodes, a transistor, and an IC into a circuit and then test each section.

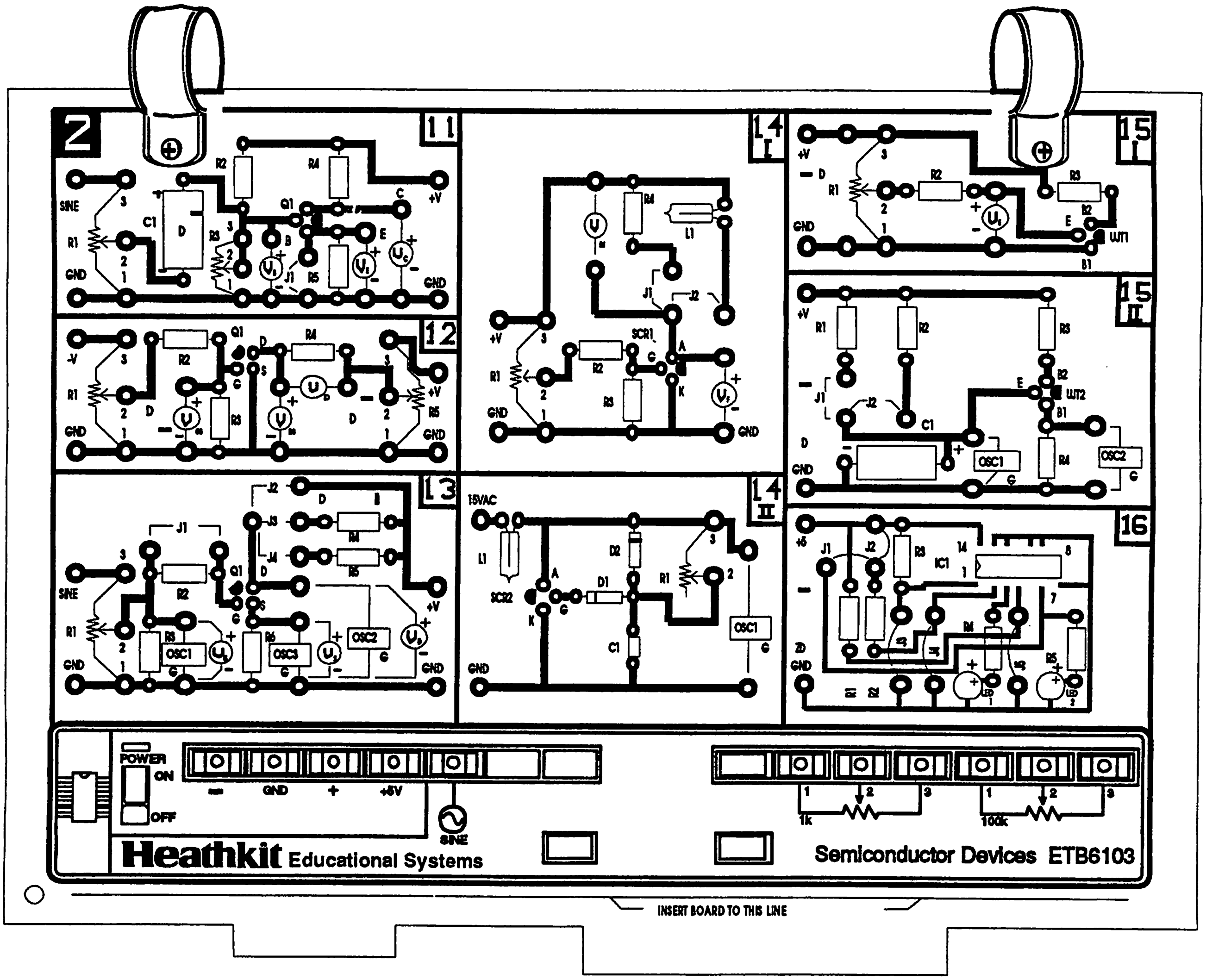
A **Material Required** section at the beginning of each experiment lists the equipment needed to successfully perform an experiment. If any extra equipment is needed, it will be listed here. Most of the components required to complete the experiments are already mounted on the experiment boards. Other parts, including jumper wires, are located in the parts storage tray included with the circuit boards. You will also need a dual-trace oscilloscope with a pair of ×1 probes, a frequency counter, and a VOM. If you use ×10 probes with your oscilloscope, be sure to change the "input volts" setting on the scope by a factor of ten.

The **Unit Examinations** have been provided to allow you to test your understanding of the material in each unit of the textbook. These examinations should be completed after you have read all sections in the unit, answered the Self-Test Review questions, and finished the related experiments.

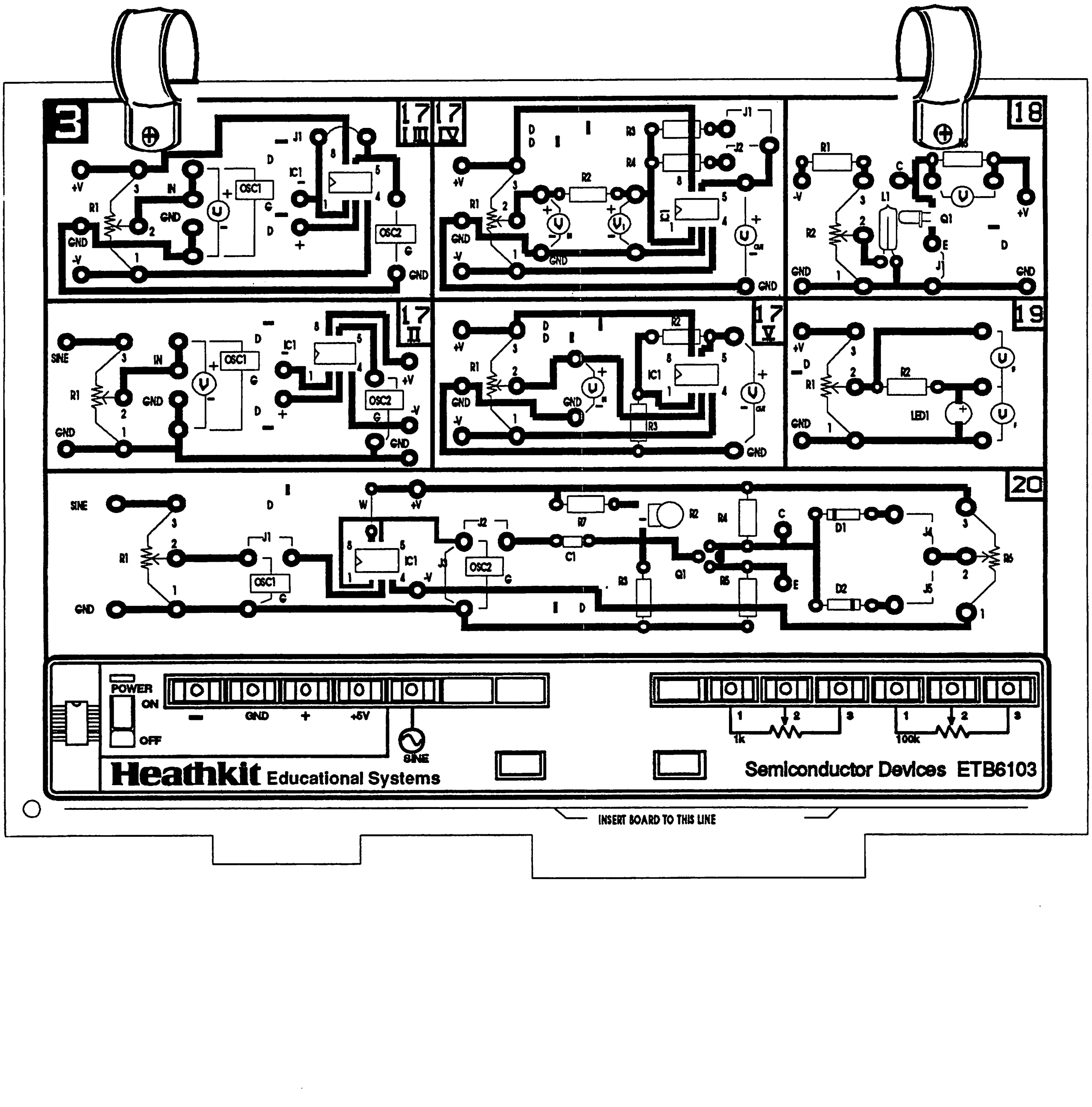
Circuit Board Pictorials



ETB-6103
Circuit Board #1



ETB-6103
Circuit Board #2



ETB-6103
Circuit Board #3

Course Purpose

This workbook and accompanying circuit boards support and reinforce the material presented in Heathkit Educational Systems' Semiconductor Devices Course. Specifically, this workbook:

1. Identifies the basic equipment used to perform the experiments.
2. Provides experience operating the Heathkit Analog and Backpack trainers and a dual trace oscilloscope.
3. Illustrates the practical measurement of AC voltages and waveforms.
4. Investigates the characteristics of typical germanium and silicon diodes.
5. Demonstrates a practical method of testing semiconductor diodes.
6. Examines half wave and full wave rectification.
7. Shows how to measure the characteristics of a zener diode and use it as a voltage regulator.
8. Shows how to test NPN and PNP transistors and identify unknown transistor leads.
9. Allows you to observe and measure some of the electrical characteristics of common-emitter, base, and collector amplifiers.
10. Analyzes an NPN transistor amplifier.
11. Demonstrates the operation of an FET, FET amplifier, SCR, and a UJT.
12. Introduces digital ICs and analyzes an operational amplifier.
13. Demonstrates the operation of a phototransistor.
14. Examines the operation of an LED.
15. Shows the operation of 3 basic types of solid state components in a circuit.

Experiments

Introduction

Before performing each experiment, read the procedure steps to make sure you understand what is to be done. Follow all directions carefully. When you have finished all of the procedure steps, review your notes and decide what you observed or learned from each experiment. Then read the experiment summary to ensure that your data and conclusions are true and accurate.

Before beginning this course, you should have completed the introductory EB-6101-71 DC Electronics and EB-6102-71 AC Electronics courses. Or, at least, have acquired an equivalent knowledge contained in these courses. This course is structured the same as the two introductory courses and will be familiar to you.

However, the instruction steps will not be as detailed as you have previously experienced. When you are instructed in a step to make a measurement reading, you must determine where to connect your test leads. You will not be directed to place the red meter test lead on TP1 or the scope probe on TP3. Although not stated in the steps, all necessary test points are included in the experimental circuits and are appropriately labelled (for example: V_1 for a voltmeter connection, OSC2 for an oscilloscope connection, etc.). To help you remember this method, the first test measurement will include the name of the test point. As you have progressed this far in your studies, you should be familiar enough with your test equipment to make all the required test measurements as instructed without any difficulty.

Also, unlike the previous DC and AC Electronics courses, only the circuit and components will be included in a block for an experiment. The schematic for the circuit will only appear in the workbook.

You are also expected to observe all the safety rules you have learned. This includes removing power from a circuit when connecting or disconnecting test equipment. Even when you are not instructed to do so, these rules must be followed to protect you and your equipment.

You may notice several unnumbered diodes (marked D or ZD) installed inside the experimental blocks. These diodes protect voltage-sensitive components from incorrectly applied voltages. They do not affect any circuit and you can disregard them while doing an experiment. Also, they will not appear in a schematic for an experiment.

General Tips for Improving the Accuracy of Your Experiments

1. Be sure that all powered equipment is connected to the same power source. This will establish a common reference and prevent ground loops.

2. Make sure you do NOT inadvertently insert a ground into the circuit under test. This could occur, for example, if your test equipment reference (ground) lead is earth grounded.

   Use an ohmmeter, set to R × 1, to see if the test equipment reference lead is earth grounded. Measure between reference lead and the center prong on the power plug. If the reading is zero, your equipment is earth grounded. If it is earth grounded, all measurements MUST be referenced to ground.

3. Remember; the frequency dial of the Trainer's Generator represents only a relative value. If you want greater accuracy, monitor the output frequency with a calibrated frequency counter or oscilloscope.

Experiment 1
Evaluating Your Lab Equipment

Purpose

1. To evaluate the equipment that will be used in your experiments.
2. To measure resistance and voltage using the Trainer's built-in multimeter.
3. To measure AC voltages using the multimeter and an oscilloscope.
4. To measure and observe AC outputs and their frequencies using a frequency counter and an oscilloscope.

Introduction

This experiment is similar to Experiment 1 in the DC Electronics course. If you did this experiment and you are still using the same equipment, you may want to skip directly to step 17. If you missed the DC course experiment, this one will introduce you to your test equipment.

To do the experiments in this workbook, you will be using the ETB-6103 with its three circuit boards and associated components. You'll also be using two other important instruments: the ETW-3600 Analog Trainer and the ETW-3567 Accessory Backpack with its built-in digital multimeter. In addition, you'll need a dual-trace oscilloscope, frequency counter, and a VOM.

The three circuit boards of the ETB-6102 contain blocks of experiments. Each block is labelled with the number and section of its corresponding experiment in this laboratory workbook. Each block contains an experiment consisting of electronic components. A jumper wire or wires, connected as instructed in the experiment, may be needed to complete a circuit. Certain experiments will require extra parts or materials that will be listed in a "Material Required" section of the experiment.

Each circuit board is designed to slide into the upright holders of the Backpack. This connects the circuit board to the Backpack and holds it at a convenient working angle while you perform the experiments. The Backpack mounts directly to the Trainer and features a built-in digital multimeter that you will use to make various test measurements. The Trainer, besides supplying power to the Accessory Backpack and circuit boards, provides other on-board components for use in the experiments.

All three circuit boards have, at the bottom, an Interface Panel. On this panel are located a number of terminal points that will be used during the experiments. The GND terminal permits connection to the Trainer's ground. The terminal labelled SINE is an output controlled by the Trainer's RANGE switch and variable frequency control. The amplitude from this output terminal is constant. The six terminals on the right side of the Panel are the 1 kΩ and the 100 kΩ potentiometer terminals, also controlled from the Trainer.

Also on the Panel are located a power ON/OFF switch and a power LED (light emitting diode) indicator. Positive (+), negative (−), and +5-volt power supply output terminals are also located on the left side of the Panel. The power outputs are controlled by the DC POWER SUPPLY control knobs on the ETW-3600 Trainer (the +5 volt output is constant). However, power is not applied to the Panel's power supply terminals until the circuit board power switch is turned ON. The Trainer's POWER switch must be ON, for power to be applied to the Backpack, and to the circuit board power switch.

In the middle of Circuit Board #1's Panel is a special converter circuit. In several experiments, you'll use it to make resistance measurements. Use the four center terminals to connect the converter between the component your measuring and the Trainer's multimeter. The left two terminals are connected across the component. The right two converter terminals connect to the multimeter. To measure resistance, the meter must be set to the DCV position and to the lowest range (2V). Set the converter circuit's range switch to either "k" or "M" for a display on the meter to be read in kilohms or megohms. The converter circuit translates the ohms value to a voltage that is read by the meter. The meter then displays the measurement that is read as an ohms value. For example, if the Panel converter switch is set to "M" and the meter displays 1.500, then the measured resistance value equals 1.5 megohms.

The ETW-3567 Accessory Backpack (with its built-in digital multimeter) is designed to be permanently attached to the Analog Trainer. Mounting hardware is supplied with the Backpack. If your Trainer is not presently fitted with a Backpack, refer to the Backpack Owner's Manual and attach it to the Trainer.

From this point on, it will be assumed that you are performing all experiments with the ETW-3567 Accessory Backpack properly installed onto the ETW-3600 Analog Trainer.

This experiment will start your lab assignments by verifying that your test equipment and the Trainer are operating properly.

Material Required

1 ETW-3600 Analog Trainer
1 ETW-3567 Accessory Backpack
1 ETB-6103
    1 Board #1
    1 Board #2
    1 Board #3
1 Parts Storage Tray
    2 Terminal connectors (with wire loop)
    1 Red positive power supply jumper wire
    1 Green negative power supply jumper wire
    1 Black ground jumper wire
    3 Blue jumper wires (for use with 1 kΩ terminals)
    3 Orange jumper wires (for use with 100 kΩ terminals)
    4 White jumper wires
    3 Gray jumper wires (with bare ends)
    2 Yellow jumper wires
    2 Violet jumper wires
1 Dual-trace oscilloscope
1 Frequency counter
1 VOM

Procedure

1. Inventory the items listed in the "Material Required" section. Place them within easy reach of your lab position. NOTE: If you do not have all the items listed in the inventory, notify your instructor before you proceed.

2. Locate the user manuals for the ETW-3600 Analog Trainer and the ETW-3567 Accessory Backpack. Read the user manuals and become familiar with the controls, features, and capabilities of these test instruments that you will be using for all the experiments in this laboratory workbook.

Discussion

In the first part of this experiment you inventoried the equipment and materials necessary to perform the following experiments. As a rule, you'll need to exercise certain precautions, and take proper care of these materials. This includes making certain that all powered equipment is turned off at the conclusion of each lab session. Specifically, be sure to turn off your Trainer and any other equipment you may have used during an experiment. If each lab station is wired to a master cut-off switch, this should be switched to the OFF position. Also, any extra loose components or equipment should be returned to their proper storage locations. The lab station should be neat and orderly when not in use.

In the preceding steps you were instructed to locate and examine the user manuals for your Analog Trainer and its Accessory Backpack. Become familiar with their features and capabilities. This is important information because as a technician you'll need to refer to technical information often. As you learn more about electronics, and electronic equipment, questions will arise about the capabilities and specifications of the equipment that you'll be using. Often, this kind of information is contained in the operator's, service, or user's manual for the equipment. It is a good idea to get into the habit of knowing how to obtain such information.

Finally, you should always be aware of the location of reference/data books, parts, and safety equipment such as fire extinguishers, the main power cut-off switch, the first aid kit, etc.

To prepare you for the other experiments in this workbook, this experiment will help you become familiar with two test instruments that are part of your lab equipment — the ETW-3600 Analog Trainer and the ETW-3567 Accessory Backpack. The ETB-6103 Circuit Boards will not be used in this experiment. This experiment is also designed to familiarize you with the oscilloscope and frequency counter.

Procedure (Cont.)

3. Place the Analog Trainer with the attached Accessory Backpack on your lab station. Do not plug the Trainer in at this time. Examine the Trainer and become familiar with its different sections. The power supply block provides DC voltages that are variable between approximately 1.2 and 15 volts both in the POS (+) and NEG (–) directions. Later in this experiment, you will measure these voltages. The Trainer also provides a center-tapped 30-volt AC supply with two 15-volt AC terminals. The frequency of the AC supplies is 60 Hz. This is the same frequency as the supply voltage that your Trainer will be plugged into later in this experiment. You also should notice that your Trainer has a generator block that provides both a sine wave and a square wave output. The amplitude of the output of the generator may vary from one Trainer to another. For discussion purposes, we will assume it is 6.36 volts effective, or 18 volts peak-to-peak. The generator also provides outputs at a variable frequency between 200 Hz and 20 kHz. To complete the introduction to your Trainer, notice that there is a 1 kΩ and a 100 kΩ potentiometer available.

Discussion

The controls (potentiometers) on the Trainer are all general purpose controls with a tolerance of 30%. You should have noticed that between the various outputs there is a GND terminal. The GND terminal is where the output is referenced. The Heathkit trainers all have the GND terminals connected internally. You should have noticed the indicator next to the power switch. This indicator is your best warning of when the Trainer has power applied to it. This provides a safety feature for the circuits and their components. Some components may be damaged, if removed or installed while power is applied. A good practice to follow is **never** make changes in your circuit, with power applied. Furthermore, the indicator light offers a degree of operator safety. On some equipment, there are harmful or lethal (death causing) voltages and currents present. In such cases, the indicator light is primarily for operator safety. The Heathkit trainers are very low powered and are not normally considered hazardous to the operator. However, there is sufficient current available to damage some components used in the experiments.

Procedure (Cont.)

4. Examine the Accessory Backpack and become familiar with its range and function switches, digital display, and input jacks.

5. Locate the red (for positive) and black (for negative) test leads for your multimeter. If not already done, plug the red test lead into the red (positive) input jack on the side of the Backpack, and plug the black test lead into the black (negative) input jack.

6. With the test leads properly connected, set the multimeter to measure resistance. To do this, slide the Backpack's FUNCTION switch (on the right side of the Backpack) to the kΩ position and the RANGE switch (the switch closest to the meter display) to the 2 V/mA/kΩ position.

Discussion

On the Backpack, the setting of the RANGE switch determines the upper limit or value the meter can safely measure. Before a measurement is made, you should have some idea of the value to expect. Then, select the lowest range that will safely measure that value. When the value is unknown, always set the RANGE switch to its highest setting. Then you can lower the range setting until the proper display is obtained.

REMEMBER: Never select a range with an upper limit lower than the value to be tested. To do so might damage your test equipment or harm you.

The FUNCTION switch setting determines the type of value to be measured. To measure resistance, set the switch to the kΩ position. To measure current, set the switch to the mA position. To measure DC voltage, set the switch to the DCV position. And finally, to measure AC voltage, set the switch to the ACV position.

Now let's use the Backpack's multimeter to make some simple resistance measurements.

Procedure (Cont.)

7. Make sure the Trainer's power switch is in the OFF position and then plug in its power (line) cord.

8. Locate two gray jumper wires (with bare ends). Insert one end of a wire into the GND terminal on the Trainer between the DC supply outputs. Connect the black lead of your multimeter, set to measure resistance, to the other end of the wire. Insert the second gray wire into the AC GND terminal and connect the positive lead of your multimeter to it. Switch the Trainer ON. What does your multimeter indicate? _______ ohms

9. Move the wire connected to the + meter lead from the AC GND to the GND terminal on the generator block. What does your multimeter indicate? _______ ohms

NOTE: The next 3 steps are performed with power removed from your Trainer, making its built-in multimeter ineffective. Therefore, you must use a VOM set to measure ohms to make the indicated measurements.

10. Turn the Trainer off and unplug its power (line) cord from the AC outlet. Examine the power plug. How many prongs does the Trainer's power (line) plug have? Number of prongs on Trainer power plug = ___ .

11. Measure the resistance between your Trainer's round center (ground) prong of its power plug, and the Trainer's various ground (GND or ⏚) blocks. Use one of the gray jumper wires, connected to one of the meter leads, to access each of the Trainer ground blocks. Measure the resistance between the prong and the listed ground blocks and record the result.

Prong to POWER SUPPLY GND _____ ohms

Prong to LINE FREQ GND _____ ohms

Prong to GENERATOR GND _____ ohms

Are your Trainer's GND (⏚) blocks common grounded? _____ .
yes/no

12. Connect a gray wire to each meter lead. Move the gray wire with the + meter lead attached into all the terminals that you did not check in steps 8 and 9. The reference, or –, lead should be connected to one of the GND terminals at this time. If a test point has an associated control, rotate that control fully clockwise (cw) and counterclockwise (ccw) while you observe the meter's indication for that particular test point.

Discussion

In steps 10 and 11 you examined the power plug of the Trainer and verified whether the Trainer's ground terminals are connected to AC ground. You should have also determined that all Trainer blocks labelled GND, or identified by the ground symbol (⏚) are electrically common. Knowing the grounding method of the Trainer (and any other piece of equipment you might work with) is important for reasons that will become clear as you progress through this course. For now it is sufficient to know that all the ground points on the Trainer are common.

When you measured the resistance of the other terminals to ground in step 12, you should have found that they were open, except for the POS and NEG terminals. These were just under 200 ohms with their respective level controls turned fully counterclockwise. The 15 volt AC outputs also had a low (but not shorted) reading. This is because you are reading across the secondary of a transformer. As you know, a transformer winding is an inductor, and the only DC resistance of an inductor is the resistance of its wire.

Next, you will verify that the 4 pins in a vertical row in the solderless terminal block are shorted together. In addition, you'll check the actual resistance of the Trainer's potentiometers.

Procedure (Cont.)

13. Plug the Trainer back in and switch the power on. Set your Trainer's multimeter to measure resistance. Then insert a gray wire into the top hole of the Trainer's GENERATOR GND solderless terminal block and connect the black meter lead. Attach the other gray wire to the red meter lead and connect it to the hole directly under the black reference lead. Note the meter's indication. Move the red meter lead to each of the remaining holes below the reference lead and note the meter's indication.

14. Next, connect the multimeter (set to the 200 kΩ range) between terminals 1 and 3 of the 1 kΩ potentiometer and rotate the control. Record the results below. Move the lead from terminal 1 to terminal 2 and rotate the control fully cw and ccw. Record your highest and lowest readings. Repeat this step using the 100 kΩ potentiometer. Switch the Trainer OFF.

pins 1 & 3 of 1 kΩ control ______ ohms.

pins 2 & 3 of 1 kΩ control cw ______ ohms.

pins 2 & 3 of 1 kΩ control ccw ______ ohms.

pins 1 & 3 of 100 kΩ control ______ kilohms.

pins 2 & 3 of 100 kΩ control cw ______ kilohms.

pins 2 & 3 of 100 kΩ control ccw ______ kilohms.

Discussion

In step 13, you verified that the 4 pins in a vertical row of a solderless terminal block are shorted (interconnected) together. In step 14, you should have proved that the high readings (pin 1 to 3) were within 30% of the value marked on the Trainer's front panel. You also should have noticed that with the meter connected between pins 1 & 3, rotating the control had no affect on the meter reading. When the meter is connected between pins 2 & 3, the control could be adjusted between a low resistance and another resistance somewhat higher than your previous maximum reading. Depending on whether the black or red meter lead was connected to pin 2, the resistance either increased or decreased when you rotated the control. It is common in electronics to have cw rotation increase the measured value. By simply reversing the leads (pins 1 & 3) the direction can be reversed. The potentiometers could have measured anywhere between:

1 kΩ pot (171 Ω–1531 Ω).
100 kΩ pot (2.1 kΩ–132.3 kΩ).

Next you'll see how your Trainer provides both positive and negative voltages relative to ground.

Procedure (Cont.)

15. Rotate the DC supply controls fully ccw. Set the multimeter to measure + DC voltage up to 20 volts. Use the gray jumper wires to connect the meter's negative lead to GND and the positive lead to the POS terminal. Switch the Trainer ON and record the minimum reading below. Then slowly rotate the POS control cw and record the voltages at the +5, +10, and +15 (maximum) voltage settings below.

+DC ccw ______ volts (min).

+5 volts ______ volts.

+10 volts ______ volts.

+15 volts ______ volts.

+DC cw ______ volts (max).

16. Move the positive meter lead to the NEG terminal. Slowly rotate the negative voltage control cw and record the voltage readings at the –5, –10, and –15 (maximum) settings below. Turn the Trainer OFF.

–DC ccw ______ volts (min).

–5 volts ______ volts.

–10 volts ______ volts.

–15 volts ______ volts.

–DC cw ______ volts (max).

Discussion

In steps 15 and 16, you established the limits that your Trainer's DC values varied between. Note that the actual readings do not correspond to the voltage marks on the front panel controls. The combination of parts, the screening tolerances, the accuracy of the test equipment used, and the care with which the readings were taken all affect the actual values that you recorded. If you use the same Trainer and test equipment for each lab assignment, you can use the information recorded as references. If greater accuracy is desired, the voltage should be measured and adjusted with a meter to start each assignment and readjusted each time the circuit's load is changed.

In the next part of this experiment, you will use an oscilloscope to measure several AC waveforms. Then you will use your measurements to make a number of calculations. These calculations will help you to understand the characteristics of your Trainer's various sources of alternating current.

First, you will set up your lab station oscilloscope and then use it to observe a 15 VAC sine wave output from the LINE FREQ (line frequency) section of your Trainer. The line frequency output is located in the upper center of the Trainer. Figure E1-1 shows this section.

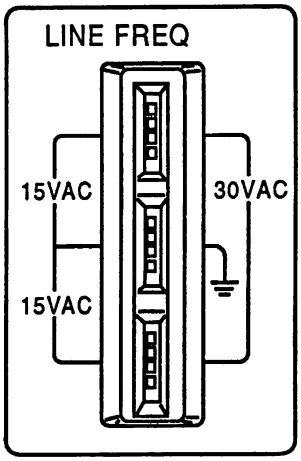


Figure E1-1
LINE FREQ section of the Trainer

Before applying power to your oscilloscope, you should make certain adjustments. The location and nomenclature for the controls shown in Figure E1-2 are for a Heathkit Oscilloscope. Since the terminology used with the oscilloscope is relatively standard, you should be able to convert these instructions to any other oscilloscope.

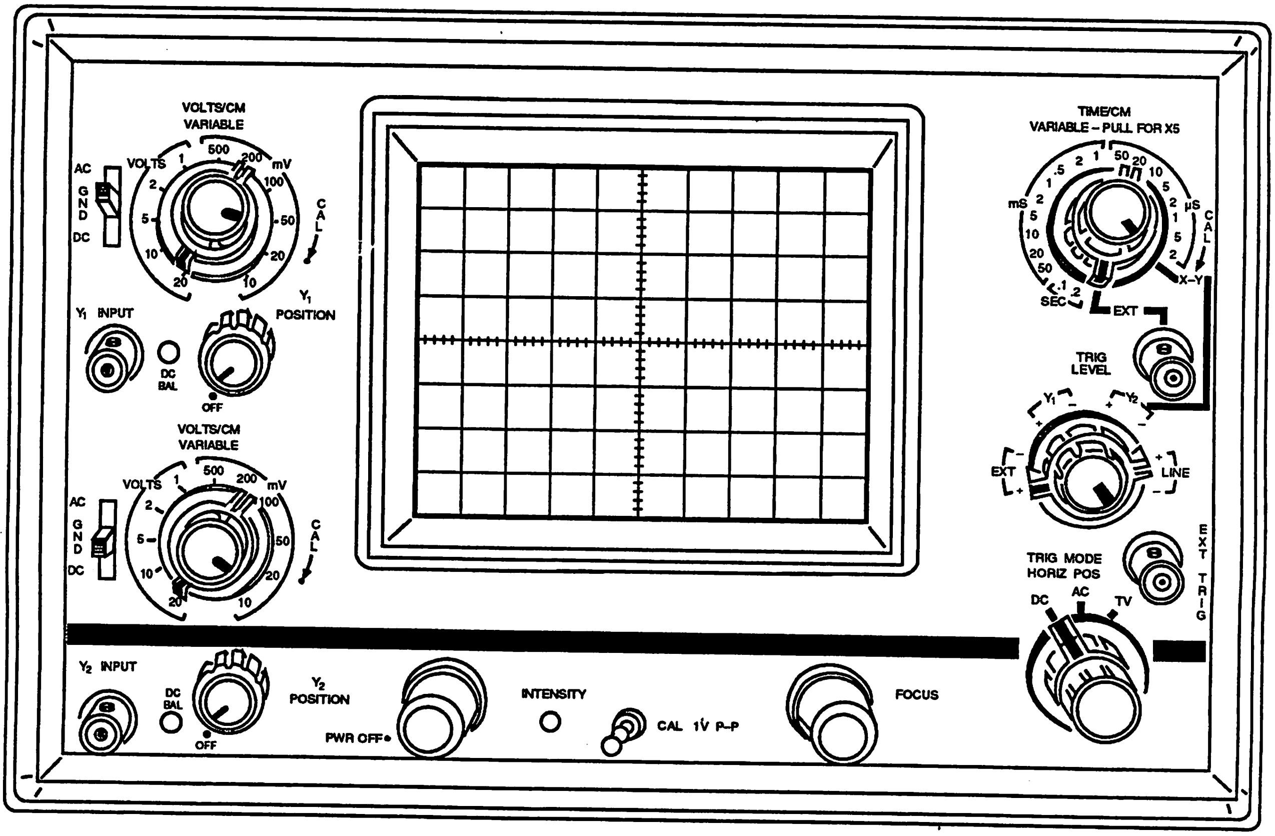


Figure E1-2
Typical dual-trace oscilloscope control panel.

Procedure (Cont.)

Set the oscilloscope controls as follows:

17. Turn the INTENSITY control to mid-range.

18. Set the TRIGGER SOURCE switch to the Y1 + position.

19. Set the TRIGGER MODE switch to the AC position.

20. Set the TIME/CM control to the 2 mS position and the SWEEP/ VAR to CAL.

21. Set the HORIZ POS control to mid-range.

22. Set the AC-GND-DC switch for both Y1 and Y2 inputs to the GND position.

23. Set the VOLTS/CM switch to 10V for both inputs and the VARIABLE to CAL.

24. Set the Y1 POSITION control to mid-range. Set the Y2 POSITION control to the OFF position.

25. Connect the oscilloscope to the proper power source.

26. Turn the POWER switch ON.

27. Allow the oscilloscope to warm up for one minute, then adjust the Y1 POSITION and the HORIZ POS controls to center the Y1 sweep on the oscilloscope display.

28. Adjust the FOCUS control for a sharply focused presentation.

Discussion

Upon completion of steps 17 through 28, the oscilloscope should be displaying a horizontal trace. The horizontal trace is called the time base. This is the part of the oscilloscope's presentation that is calibrated in increments of time and is used to measure the cycle time (period) of a waveform. Remember, that the period of a waveform is the reciprocal of frequency: period (T) = 1/F.

Procedure (Cont.)

29. Attach the probe to the Y1 VERTICAL INPUT. Note that all input voltage settings assume you are using a 1× probe. If you are using a 10× probe, reduce each voltage setting one decade (for example, 5 V/CM to 0.5 V/CM).

WARNING

WARNING: In the following step, be sure that the ground clip is NOT connected to the top or bottom terminal blocks in the LINE FREQ section. This will directly ground the output of the power transformer and will blow the power fuse inside the Trainer.

30. Set the Y1 AC-GND-DC switch to the AC position.
31. Plug in the Trainer. Make sure the power switch is in the OFF position. Turn all control knobs fully counterclockwise (ccw).
32. Insert a bare end from a gray jumper wire into the top 15 VAC terminal block of the LINE FREQ section. Connect your oscilloscope probe to the other bare end of the wire. Insert the bare end of a second gray jumper wire into the middle ⏚ terminal block. Connect the ground clip from the probe to the free bare end. The connection is shown in Figure E1-3.

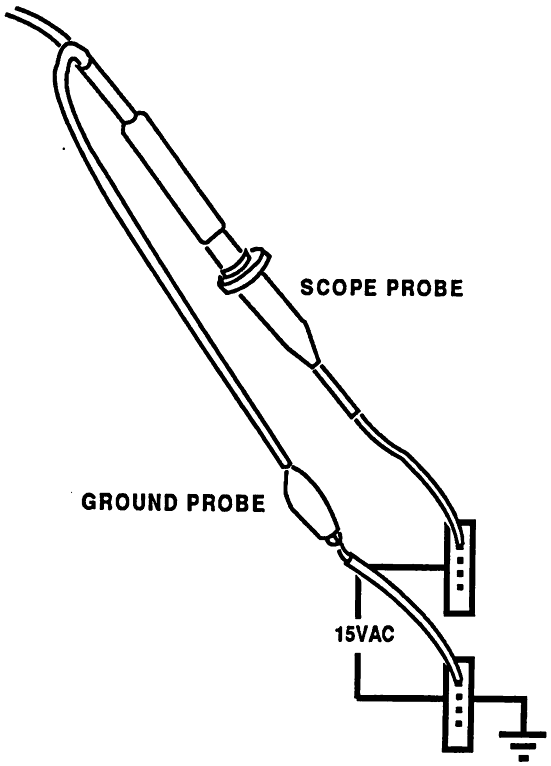


Figure E1-3
Circuit connection for step 32.

33. Make sure that the oscilloscope TIME/CM switch is set to the 2 ms-per-centimeter position. However, any setting of this control which provides from one to three complete waveforms will be adequate for this experiment. All oscilloscopes do not have a 2 ms/CM horizontal range.

34. Switch the Trainer ON. You should now have a oscilloscope presentation similar to that shown in Figure E1-4.

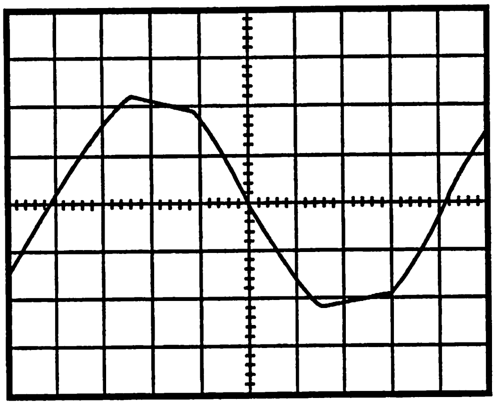


Figure E1-4
Typical sine wave display.

Discussion

The waveform shown on your oscilloscope is a sample of the line frequency signal applied to the power supply of the Trainer. The waveform may or may not appear clipped (flattened) at the peaks of the signal. If it is clipped, this is due to the electrical characteristics of the Trainer and will have no major effect on the next portion of this experiment. When a waveform is clipped, the clipping is referred to as distortion.

Procedure (Cont.)

35. Determine the horizontal width, in centimeters (cm), of one cycle of the waveform displayed on the oscilloscope screen. The signal is __________ cm wide.

    Now determine the period of the waveform displayed on the screen. The period (T) is _________ milliseconds (ms).

36. Now that you have determined the period of the AC waveform, it is possible to calculate the frequency of the signal. The frequency (F) is ________ Hz.

37. Turn your frequency counter on and set it to measure Hz. Connect the counter's input probe to the same 15 VAC terminal block as the oscilloscope is connected. Connect the counter's ground lead to a Trainer ground block. The frequency (F) is _________ Hz.

38. Observe the waveform on your oscilloscope. Determine the height of one alternation of the waveform in centimeters. The height is ___________ cm.

39. Using the height of the AC waveform from the previous step, calculate the peak amplitude of the AC waveform. The peak amplitude of the signal is ________ volts.

40. Calculate the peak-to-peak voltage of the AC signal. The peak-to-peak voltage is _________ volts.

    If you have any problem with the preceding three steps, refer to the following discussion.

41. Refer to the peak voltage calculated in step 39. Is there any difference between this value and the stated 15 VAC output from the LINE FREQ section of the Trainer? _________ (yes/no). Switch Trainer power OFF.

    If the answer is yes, explain why it is different. ________________
    ____
    ____.

Discussion

Each graticule square etched on the face of the oscilloscope is 1 centimeter by 1 centimeter. To determine the horizontal width of one cycle of an AC waveform, count the number of graticules encompassed by a cycle. In the case of the example waveform, one cycle of the displayed signal is approximately 8.3 cm wide.

Once you have determined the width of the waveform, you must multiply the width by the setting on the TIME/CM control to determine the period (time of one cycle) of the signal. During the experiment, the TIME/CM control was set to 2 ms. Therefore, the period of the signal is:

$$8.3 \times 2 \text{ ms} = 16.6 \text{ ms.}$$

Once the period of the signal is known, the signal frequency is calculated to be 60 Hz, using the formula $F = 1/T$.

This is the line frequency of the Trainer. It is possible to calculate the frequency of any AC signal using this method.

By connecting the frequency counter to the same point as the oscilloscope, you could directly read the signal frequency without the need to calculate it. While using a frequency counter allows you to quickly determine a signal's frequency, you have proved that an oscilloscope provides the same accuracy in frequency measurement capability. This is another advantage of the oscilloscope.

It is also possible to calculate the amplitude of an AC signal with an oscilloscope. To do this, you must first know the height of one peak of the AC waveform. The height of the 15 VAC output is between 2.0 and 2.2 cm.

Once the height is known, it is a simple matter to determine the actual peak voltage. Just multiply the height of the signal in centimeters by the setting on the VOLTS/CM control. A typical peak AC signal for the Trainer is 21 volts.

Since 21 volts is the peak voltage, you can determine the peak-to-peak value by multiplying the peak value by 2.

The calculated peak voltage of 21 volts, is significantly larger than the 15 VAC labelled on the Trainer. This is because the output of the power supply is given in effective (rms) volts. To calculate the effective voltage of a signal that has a 21-volt peak, you multiply the peak value by 0.707.

Remember, unless otherwise stated, AC voltages are normally considered to be effective (rms) values.

Summary

This experiment introduced you to the lab equipment you'll be using in the remaining experiments. You identified the lab equipment, examined the features of your Trainer, and made some basic measurements with the Backpack multimeter, oscilloscope, and ohmmeter. With this information, you are now ready to experiment with AC electronics.

Experiment 2
Semiconductor Diode Characteristics

Purpose

1. To investigate the characteristics of typical germanium and silicon semiconductor diodes.

Introduction

Experiment 2 is located in Block 2, 3 in the upper left corner of Circuit Board #1, as shown in Figure E2-1. All jumper locations mentioned in this experiment will refer to this block or to the Circuit Board Interface Panel.

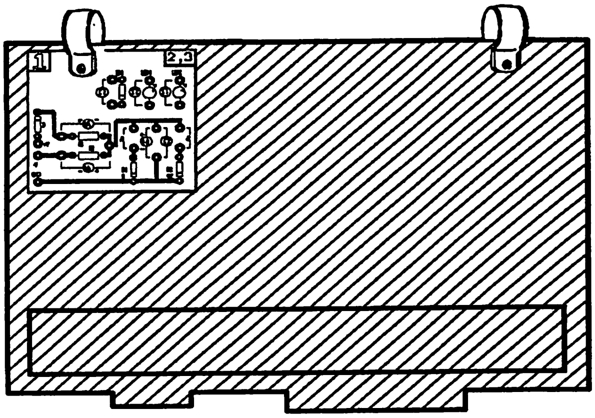


Figure E2-1
Block 2, 3 of Circuit Board #1.

Semiconductor diodes conduct current well in one direction but very poorly in the other. Their forward conducting resistance is low and when reversed biased their resistance is high. This unilateral characteristic is typical of nearly all semiconductor diodes. However, the specific characteristics of such diodes vary widely. In this experiment, you will investigate the characteristics by plotting V-I (voltage vs current) curves for typical germanium and silicon diodes.

Material Required

- 1 ETW-3600 Analog Trainer
- 1 ETW-3567 Accessory Backpack
- 1 ETB-6103
  - 1 Board #1
  - 1 Red jumper wire
  - 1 Green jumper wire
  - 1 Black jumper wire
  - 1 White jumper wire

Procedure

1. Plug in your Trainer, but be sure that the unit is turned off at this time. Make sure all the Trainer controls are turned fully counterclockwise. Then install Circuit Board #1 into the Backpack's circuit board holder.

2. Construct the circuit shown in Figure E2-2. To connect the Trainer's power supply, install a red jumper wire from the Interface Panel's + (positive) terminal to +V in Block 2,3. Then install a black jumper wire from Panel GND to GND in the block. To complete the circuit, install a white jumper wire at J1. Remember that the GND (ground) terminal on the Interface Panel is common to both the positive (+) and negative (–) power supplies. (The green jumper wire will be used later.)

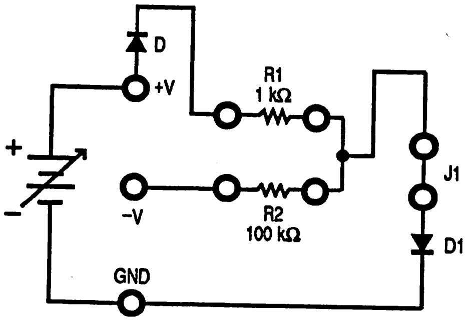


Figure E2-2
Circuit for Experiment 2.

3. Set up the Backpack's multimeter to measure +DC voltage in the 2 volt range. Connect the meter test leads across R1 (V_1) to measure its voltage drop.

4. In this part of the experiment, the variable supply will forward bias diode D1. Diode D protects D1 from incorrect applied voltages and will not affect the circuit. Turn on your Trainer and then switch Board #1 power ON.

5. Turn the Trainer's positive (+) voltage control clockwise until the meter indicates that the voltage across R1 is 0.1 volts. According to Ohm's law, the voltage across R1 (0.1 volts) divided by the resistance of R1 (1000 ohms) is equal to the current through R1. The current must therefore be equal to 0.1 volts divided by 1000 ohms or 0.0001 amperes, which may also be expressed as 0.1 milliamperes. Since R1 and D1 are in series, and current is constant in a series circuit, the forward current (I_F) through D1 must also be 0.1 milliamperes at this time.

6. Switch Board #1 OFF and connect your meter to measure the voltage drop across the diode (V_3). Switch Board #1 ON and note the indicated voltage. Record this voltage in the table in Figure E2-3 immediately below the forward current (I_F) value of 0.1 milliamperes. Notice that appropriate spaces are provided for both silicon (Si) and germanium (Ge) diodes. Your recorded value represents the forward bias voltage (V_F) across the diode when I_F is equal to 0.1 milliamperes.

7. Now fill in the first half of the table in Figure E2-3. Adjust I_F to 0.2 mA, 0.3 mA, 0.4 mA, and 0.5 mA and record the corresponding values of V_F. Use the same basic procedures described in steps 5 and 6 above keeping in mind that different values of I_F and V_F are involved. Measure each V_F value as accurately as possible. You will save considerable time in completing the table if you simply consider the fact that I_F varies proportionally with the voltage across R1. Therefore, if I_F equals 0.1 milliamperes when the voltage across R1 equals 0.1 volts, I_F values of 0.4 and 0.5 milliamperes will correspond to voltages of 0.4 and 0.5 volts across R1. This makes it possible to convert the voltage developed across R1 directly into milliamperes.

8. After recording the first five V_F values (0.1 mA to 0.5 mA), reset your meter to the 20V range. With your meter connected across R1, advance the (+) power supply control clockwise until the meter indicates 1.0 volt across R1. Complete the table in Figure E2-3 by adjusting I_F to the remaining values indicated and recording the corresponding values of V_F. As you complete the table in Figure E2-3, measure each corresponding value of V_F as accurately as possible.

I_F (MILLIAMPERES)	0.1	0.2	0.3	0.4	0.5	1.0	2.0	3.0	4.0	5.0	6.0
V_F (VOLTS) — Si											
V_F (VOLTS — Ge											

Figure E2-3
Record for data from steps 6, 7, and 8.

9. Now plot the corresponding values of I_F and V_F you entered in the table in Figure E2-3 onto the graph shown in Figure E2-4. Then connect the various points plotted on the graph to form a continuous curve. This curve shows the continuous relationship between the diode's forward current and forward bias voltage. Label this curve with the appropriate letters (Si for silicon).

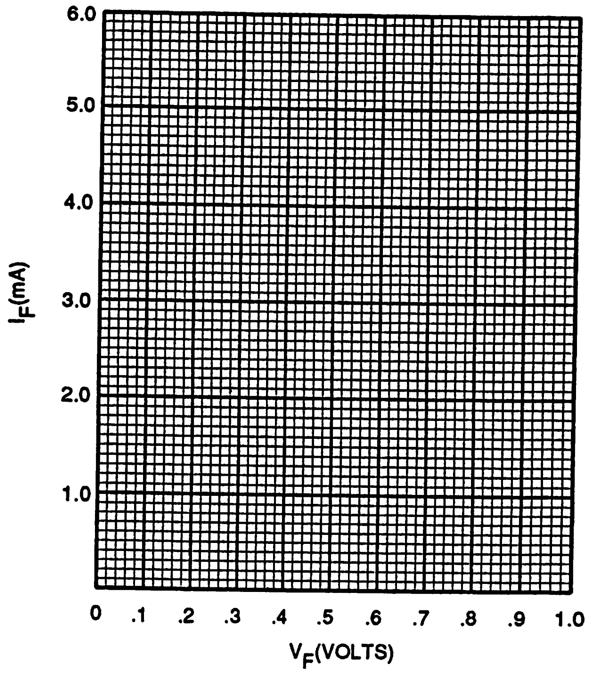


Figure E2-4
Graph for plotting I_F and V_F values.

10. Switch Board #1 OFF. Remove the red jumper wire from the +V terminal in the block. Install the green jumper between the block –V and Panel – (negative) terminals. This, in effect, reverses the connection of D1 so that it is installed in the opposite direction. This jumper change also replaces R1 with R2, a 100 kilohm resistor. Your circuit should now appear as shown in Figure E2-5. D1 is now connected so that it will be reverse-biased when voltage is applied to it through R2.

11. Connect the meter's test leads across D1. You will now use your voltmeter to measure the reverse bias voltage (V_R) across D1. Switch Board #1 ON and turn the voltage control of the negative (–) power supply clockwise until the meter indicates that the diode's reverse bias voltage is equal to 12 volts.

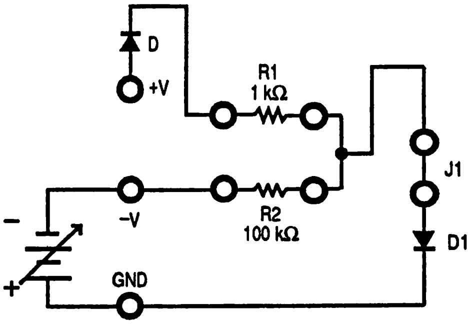


Figure E2-5
Circuit for steps 10, 11, and 12.

12. Without disturbing the voltage setting, use your voltmeter to measure the voltage across R2. Using the measured voltage, calculate the amount of current flowing through R2.

$$I = \frac{V_{R_2}}{R_2}$$

$$= \frac{V_{R_2}}{100000}$$

Since R2 and D1 are in series and D1 is reverse biased, your calculated current represents the reverse current (I_R) flowing through D1. Record the reverse current value (in microamperes) in the appropriate space in the table in Figure E2-6. Your recorded value represents the amount of reverse current flowing through D1 when V_R equals 12 volts. The reverse current should be very low and for some diodes it may be too low to measure. If you can't detect any current assume that it is zero. If you can detect the voltage drop across R2, then calculate the value of reverse current flowing through and R2 and record it in the chart shown in Figure E2-6.

V_R = 12 VOLTS	
I_R (MICROAMPERES) - Si	
I_R (MICROAMPERES) - Ge	

Figure E2-6
Record for data from steps 11 and 12.

13. Switch Board #1 OFF. Remove the green jumper wire connector from the –V terminal in the block. Reinstall the red jumper onto the +V terminal. Remove the white jumper from J1 and install it at J2. Moving the white jumper removes the silicon diode from the circuit and replaces it with the germanium diode. You now have the same circuit you started with except you're now using a germanium diode (D2) in the circuit as shown in Figure E2-7.

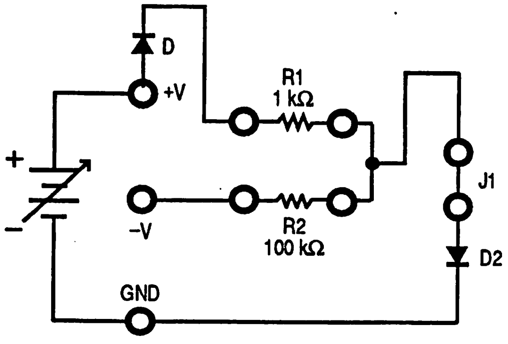


Figure E2-7
Circuit for steps 13 and 14.

14. Now repeat steps 5 through 12 using the germanium diode instead of the silicon diode. Be sure that you fill in the proper spaces in the tables shown in Figure E2-3 and Figure E2-6. Also, be sure to identify the germanium diode characteristic curve that you plotted in Figure E2-4. After you complete step 14 for the germanium diode, turn the Trainer and Board #1 OFF, and remove all jumper wires. Then read the following discussion.

Discussion

In this experiment you subjected first a silicon diode and then a germanium diode to various forward bias voltages and adjusted the diode current in steps over the 0.1 mA to 6 mA range. You then determined the corresponding forward voltage across each device. Next, you used the measured values to plot a characteristic curve for each diode. You should have found that the characteristic curves that you plotted for the silicon and germanium diodes compare favorably with the V-I curves shown earlier in the textbook (Figure 2-6 and 2-7). Your curves should show that the forward bias voltage across each diode remains relatively constant when the forward current (I_F) through each diode reaches a point where it begins to rise at a rapid rate. This point is called the knee of the curve. At this point the voltage across the silicon diode was probably in the 0.6 to 0.7 volt range while the germanium diode was probably in the 0.2 to 0.3 volt range. Below the knee of the V-I curve for each diode, little current flows. However, above the knee of the curve, the current rises rapidly with increasing applied forward voltage.

In studying the curves you plotted in Figure E2-4 it should be apparent that the voltage across the germanium diode is less than the voltage across the silicon diode. Also, it should be apparent that the forward voltage is not a fixed value. It varies in proportion to the forward current. However, the amount of change of the forward voltage over a wide range of current values is very small. For that reason, we can generally assume the forward voltage to be basically a constant for most applications.

Next, you subjected the germanium and silicon diodes to reverse voltages and measured the reverse or leakage currents through these devices. You should have found that the reverse current through each diode was extremely low and for all practical purposes equal to zero. You probably found the leakage current in the germanium diode to be less than a microampere with 12 volts across it, if you could measure it at all. You may have found the leakage in the silicon diode too low to be measured with your test set up.

This proves that the reverse resistance of the germanium diode is less than the silicon diode. It also accounts for the lower barrier voltage of the germanium diode (0.3 volts) compared to 0.7 volts for the silicon diode.

Summary

In this experiment, you proved that a silicon diode and a germanium diode conduct well in one direction. However, you saw that they conduct very poorly in the other direction. And, by plotting the V-I curves for these two semiconductor diodes, you saw that their graphed curves appear similar. However, the curves appeared at different points on the chart. From the graphs you see that the germanium diode reaches a point where the forward current (I_F) begins to rise at a rapid rate before the silicon diode. This knee of the curve is called the barrier voltage. This barrier voltage is about 0.7 volts for the silicon diode and 0.3 volts for the germanium diode. While these voltages are typical for these diodes, they are approximate and may vary between types of diodes.

Experiment 3
Testing Semiconductor Devices

Purpose

1. To demonstrate a practical method of testing semiconductor diodes.

2. To determine if the diodes in the experimental block are shorted or open.

Introduction

Experiment 3 is located in Block 2,3 in the upper left side of Circuit Board #1 as shown in Figure E3-1. All jumper locations mentioned in this experiment will refer to this block or to the Circuit Board's Interface Panel.

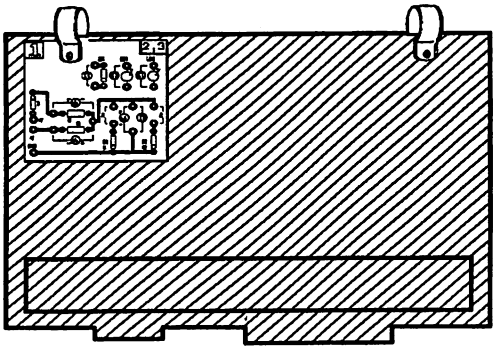


Figure E3-1
Block 2,3 of Circuit Board #1.

Semiconductor diodes can be tested by a variety of methods. Oscilloscope curve tracers and specially constructed transistor testers can be used to determine the characteristics and condition of a diode. However, in most cases diodes are tested primarily to see if they are simply shorted or open rather than to determine their detailed specifications. For that reason a simple go/no go test method is preferred in most situations. A quick and easy diode test can be made with most ohmmeters. This experiment describes the procedure and the theory used when testing diodes with an ohmmeter.

Material Required

1 ETW-3600 Analog Trainer
1 ETW-3567 Accessory Backpack
1 ETB-6103
    1 Board #1
    1 Red jumper wire
    1 Black jumper wire
    1 White jumper wire
    2 Terminal connectors (with wire loop)

NOTE

Many digital and electronic meters now provide a diode check mode, indicated by a diode symbol, in which, a constant current source instead of a constant voltage source is sometimes provided. A silicon diode or PN junction will indicate between 0.5 and 0.7 V_F. A germanium diode or PN junction should indicate between 0.2 and 0.4 V_F. In some cases, a diode is indicated, but the meter will measure ohms. This meter position is designed to measure the forward and reverse resistances of a diode at a specific voltage.

Procedure

1. With the Trainer off and all controls in their fully counterclockwise position, install Circuit Board #1 into the Backpack's holder.

2. In the first part of this experiment, you will use the special converter circuit on the Interface Panel to test silicon diode D1 in Block 2,3. Set the Backpack multimeter to its lowest (2V) range and its function switch to DCV. Connect the red and black meter test leads, and the red and black jumper wires to the Panel's converter circuit as shown in Figure E3-2. The red meter lead connects to the +DC terminal and the black meter lead connects to the −DC terminal. The red jumper wire connects to the +Ω terminal and the black jumper wire connects to the −Ω terminal. Set the converter k/M switch to the k position for the resistance reading to be displayed in kilohms.

   NOTE: Some ohmmeters (like the one in the Backpack) use a test voltage that is lower than the barrier voltage of a diode. Therefore, these ohmmeters cannot measure junction resistances. The converter circuit is included on Board #1 to enable you to make this measurement.

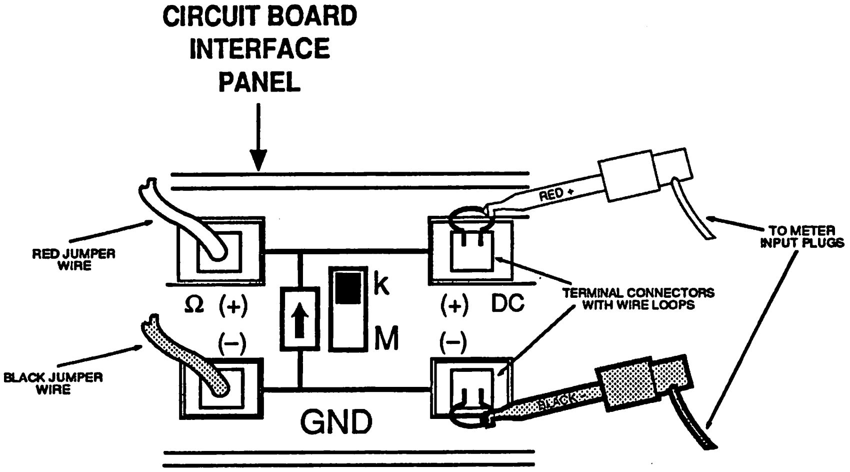


Figure E3-2
Converter circuit hookup.

3. To test diode D1, connect the free ends of the red and black jumper wires across D1 (Ω) as shown in Figure E3-3A. Install a white jumper wire at J1. Your meter is now set to measure the forward resistance of diode D1. Switch the Trainer ON. Record the forward resistance in the space provided in Figure E3-4.

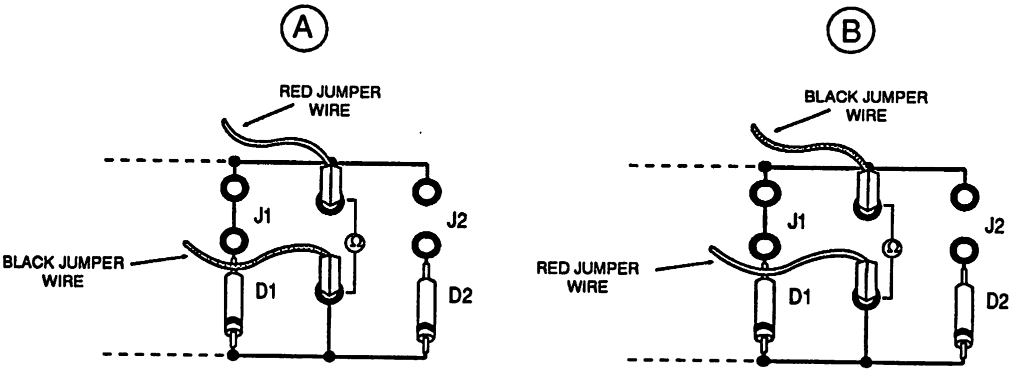


Figure E3-3
Forward and reverse resistance check of D1.

4. Now switch the converter k/M switch to the M position for the resistance reading to be displayed in megohms. (Make sure that the Backpack meter is set to DCV on the 2V range.) Then connect the red and black jumper wires across D1 as shown in Figure E3-3B. Note, that these connections are the reverse of those in step 3. You are now measuring the reverse resistance of the diode. Record the reverse resistance in the appropriate space provided in Figure E3-4. If the resistance reading displayed is greater than the measurement range of the meter (display is blank except for a 1 in the leftmost digit) enter an infinite or ∞ sign in the appropriate space.

5. Remove the white jumper wire from J1 and install it at J2. Now repeat steps 3 and 4 for the germanium diode (D2) and record the diode's forward resistance (R_F) and reverse resistance (R_R) in the table provided in Figure 3-4.

6. Using the forward and reverse resistance values in Figure E3-4, calculate the ratio of reverse to forward resistance and record in the space provided in Figure E3-4.

DIODE	R_F	R_R	R_R/R_F
Si			
Ge			

Figure E3-4
Data from steps 1, 2, 3, and 4.

Discussion

Your measurements should show that the germanium diode has a forward resistance that is between a few ohms and several hundred ohms and a very high reverse resistance that is greater than 100 kilohms and possibly as high as several megohms. The forward resistance of the silicon diode should be slightly higher than the forward resistance of the germanium diode, but again should not exceed a value of several hundred ohms. The reverse resistance of the silicon diode should be much higher than the reverse resistance of the germanium diode. In fact, your meter may have indicated that the silicon diode has an infinite reverse resistance.

The reverse to forward resistance ratio R_R/R_F gives a relative indication of how well the diode passes current in one direction and blocks it in the other. The higher this ratio the better the diode. In step 6 you should have found the ratio of the silicon diode to be much higher than that of the germanium diode. This significant difference is primarily the result of a high leakage current in the germanium device.

When using an ohmmeter, other than the converter circuit and your Trainer, to check the forward and reverse resistances of germanium and silicon diodes, it is possible to obtain only relative indications of resistance in each direction. Also, the resistance in either direction will change if you set your meter to a different resistance range. Figure E3-5A shows the equivalent circuit formed when an ohmmeter is used to check the forward resistance of a diode. Notice that the negative (–) lead of the ohmmeter is connected to the cathode of the diode and the positive (+) lead of the meter is connected to the anode of the diode. The ohmmeter, has an internal battery and an internal resistance as shown. The battery causes a small forward current to flow through the diode and also through its internal resistance. When different ranges are used, various internal resistors are switched into the circuit and the current through the diode changes. This causes the resistance of the diode to change and accounts for the various forward resistance readings that are obtained from one range to the next and also from one ohmmeter to the next. A similar situation also occurs when the ohmmeter is used to measure the reverse resistance of the diode as shown in Figure E3-5B.

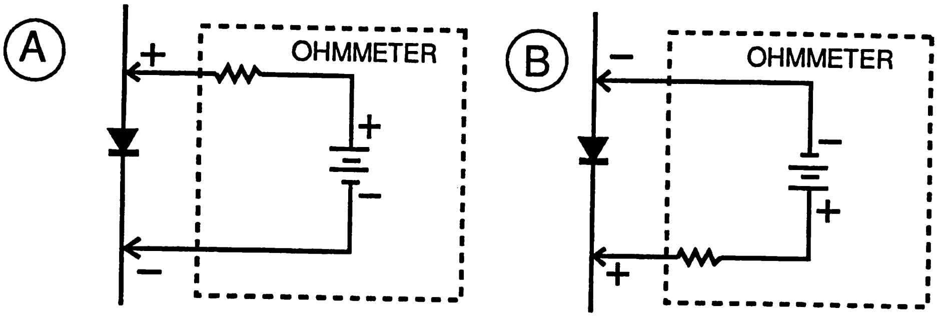


Figure E3-5
Alternate ohmmeter circuit configuration.

The ohmmeter circuit in Figure E3-5A shows the negative terminal of the internal battery connected to the negative, black or common lead. The positive battery terminal is connected to the positive meter lead. This is the arrangement in most ohmmeters and it permits you to quickly determine the polarity of the internal voltage at the ohmmeter leads. While this is a convenient and also obvious connection, some ohmmeters use the opposite arrangement where the positive terminal of the internal battery connects to the negative or common lead. If the experiment worked as described above, then your ohmmeter is connected as shown in Figure E3-5A. However, if your forward and reverse resistance measurements were opposite, then you have the ohmmeter connected as shown in Figure E3-5B. Accurate diode tests can be made with most types of analog ohmmeters regardless of the internal circuitry. You should know which circuit configuration your meter circuitry uses.

Although ohmmeter readings are only relative, they do indicate when a diode meets its basic requirements by providing a high resistance in one direction and a low resistance in the opposite direction. If a diode has an extremely low resistance in both directions it usually has an internal short and is defective. Also, when a diode has an extremely high resistance in both directions it is considered to be open and therefore defective.

Procedure (Cont.)

7. Repeat the forward and reverse measurements on the remaining semiconductor devices in the block. These devices are a zener diode (ZD1), a red light emitting diode (LED1), and a green light emitting diode (LED2). It is not necessary to plot the various values in the tables or to calculate the front-to-back ratio of these devices. This step is to illustrate that any diode is a 2-element device. Even though they have a variety of specific applications for specific diodes they can (nearly) all be tested for opens and shorts. Remember that the cathode end is always the negative end of the diode. Examine the diodes carefully. It is not always possible to see which lead is the cathode by visual inspection (all diodes are not banded). This is particularly true when examining parts in a circuit or used parts where the leads have been shortened. In these cases the ohmmeter can be a valuable aid in determining which lead is the cathode and which lead is the anode.

Summary

In Experiment 3, you demonstrated a practical method of testing semiconductor diodes. By using ohmmeter readings in a simple go/no go test method, you determined if the diodes in Block 2,3 were good, shorted, or open. This quick and easy diode test can be made with most ohmmeters.

Experiment 4
Diode Rectifiers

Purpose

1. To use the diode as a half wave rectifier.
2. To use diodes to obtain full wave rectification.
3. To compare full wave and half wave rectification.
4. To convert the pulsating DC (rectifier pulses) into a usable DC voltage.

Introduction

Experiment 4 is located in Block 4 in the lower left corner of Circuit Board #1 as shown in Figure E4-1. All jumper locations mentioned in this experiment will refer to this block, to the Circuit Board's Interface Panel, or to the Trainer.

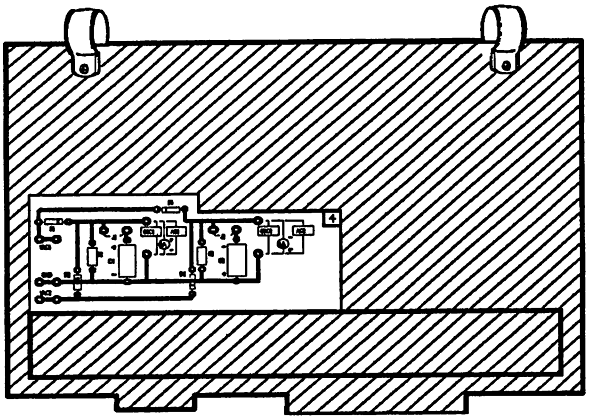


Figure E4-1
Block 4 of Circuit Board 1.

In this experiment, you will use the diode to change an AC waveform into half-wave and full-wave pulses. As you will see these pulses can be either positive or negative depending on the positioning of the diodes in the circuit. In the AC Electronics Course you learned that a sine wave consisted of alternating positive and negative half-wave pulses.

The diode by nature of its low forward resistance will pass one of the pulses when forward biased. When the diode is reverse biased, its very high reverse resistance will block the other pulse. When the diode is reverse biased it is effectively an open switch.

You will also see that, with the addition of a capacitor, these rectified pulses can be converted to an almost pure DC.

A 30-volt, 60 Hz, AC source is available at the secondary of transformer mounted inside the Trainer. The outputs of this transformer are found in the LINE FREQ section of the Trainer. Since the supply voltage to the primary of the Trainer (line voltage) is approximately 115 VAC, the transformer must be the step down variety. With the voltage at the secondary being 30 VAC, the primary to secondary ratio must be 4/1. Notice also, that it is split into two 15 VAC, 60 Hz sources. You will use both the 15 and 30 VAC supplies in this experiment.

Material Required

1	ETW-3600 Analog Trainer
1	ETW-3567 Accessory Backpack
1	ETB-6103
	1 Board #1
	1 Red jumper wire
	1 Black jumper wire
	2 Violet jumper wires
	2 White jumper wires
1	Dual-trace oscilloscope
1	VOM (optional)

Procedure

1. With the Trainer switched OFF, install Circuit Board #1 into the Backpack's holder. Use a violet and black jumper wire to construct the half-wave rectifier circuit shown in Figure E4-2. Install the pin-connector end of the violet jumper into the top 15 VAC terminal block in the LINE FREQ section of the Trainer and the other terminal end onto the VAC1 terminal in Block 4. Install the black jumper between the Panel's GND terminal and the GND terminal in Block 4.

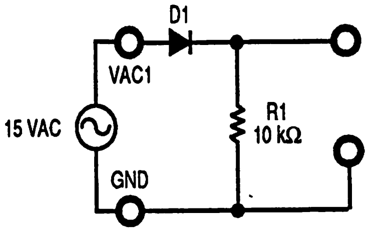


Figure E4-2
Half-wave rectifier.

2. Turn on your oscilloscope and set the controls as follows:

TRIGGERING—INT/EXT/LINE switch to LINE

TRIGGERING—SLOPE switch to the "+" position

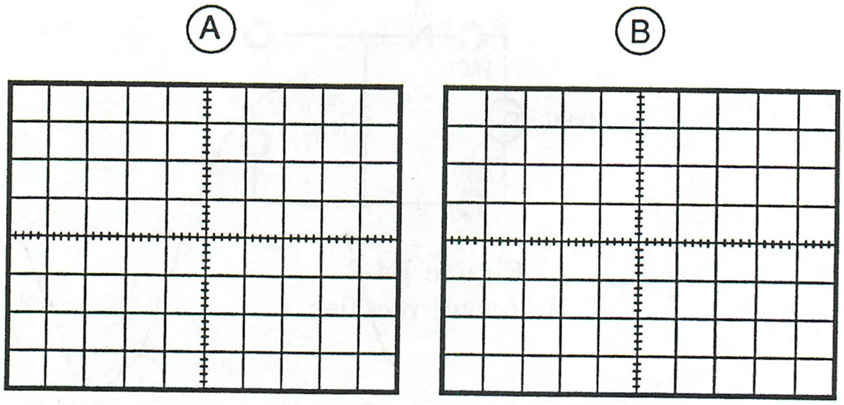
TRIGGERING—AC/DC switch to the AC position

TIME/CM—Selector to 2 ms position

Y1 and Y2 AC/GND/DC—Input switches to the AC position

Y1 and Y2 VOLTS/CM—Selectors to 5 volts

3. Turn on the Trainer. Connect the Y1 channel scope probe to the unbanded end of diode D1 (VAC1). Connect the Y2 channel probe to the banded end of diode D1 (OSC1). Connect the scope probe ground lead to GND. Switch Board #1 ON. Sketch the waveform of Y1 in the space provided in Figure E4-3A. The distortion on the input sine wave is caused by the power transformer in the Trainer. Sketch the waveform of Y2 in the space provided in Figure E4-3B. Measure the time of one cycle of the input and output waveforms, and use the formula F = 1/T to calculate the input and output frequencies.



CHANNEL Y1

T = ______________ ms

F = ______________ Hz

CHANNEL Y2

T = ______________ ms

F = ______________ Hz

Figure E4-3
Half-wave rectifier waveforms.

4. Measure the peak-to-peak amplitude of the AC signals and convert the peak-to-peak values to peak values. You may have to use the vertical positioning control on your oscilloscope to see the complete waveforms.

$E_{p\text{-}p}$ (Y1) = ________ volts

$E_{p\text{-}p}$ (Y2) = ________ volts

Switch the Trainer OFF and remove all scope and meter test leads from the circuit.

5. Set up the Backpack's multimeter to measure AC volts (or use an optional VOM). Set the range switch to the 500 VAC position and the function switch to ACV. Connect one meter lead to the unbanded end of diode D1 and the other lead to ground. Turn the Trainer on and record the AC input voltage. This is the AC effective value of the input. Turn the Trainer off again..

   E_{in} = ____________ volts

6. Confirm the relationship between peak and effective voltage by dividing E_{in} by 0.707.

   $E_P = E_{in}/0.707$ = ____________ volts

   Compare this answer with that obtained in step 4.

Discussion

In this part of the experiment, you constructed a half wave rectifier (D1 and R1) and measured the input and output voltages and frequencies. You discovered that the 15 VAC input was approximately 15 volts RMS or effective voltage (probably slightly higher) and that the frequency was 60 Hz. The peak-to-peak value of the waveform was 42 volts. The peak of the output waveform measured with channel Y2 of the oscilloscope should have been positive and approximately 21 volts. You should have noticed that the negative half cycle did not appear in the output (Y2 waveform). You found that the time of one cycle of both the input and output is 16.67 ms which converts to 60 Hz. This can easily be proven by measuring with a frequency counter if you doubt the calibration of your oscilloscope.

Procedure (Cont.)

7. Reset your meter to measure +DC volts and connect the meter between ground and the AC input (unbanded end of diode D1). Turn the Trainer on and record the meter reading below. (If the Backpack's meter reading is unstable, a VOM may be used.) Switch the Trainer off.

   E_{in} (DC) = ____________ volts

8. Reconnect the meter to the output of the circuit (banded end of diode D1). Turn the Trainer on and record the meter reading below. Switch the Trainer off.

E_{out} (DC) = ____________ volts

9. Connect your scope and the meter to the output of the negative half-wave rectifier circuit (unbanded end of diode D3). If you are using a VOM, switch it to the negative DC range. Turn the Trainer on and observe which half of the waveform has been eliminated. Now measure the –DC value of the input and output and record your measurements below. Turn the Trainer off and remove the scope probe from the circuit.

E_{in} (–DC) = ____________ volts

E_{out} (–DC) = ____________ volts

10. Install a white jumper wire at J1. This places 100-microfarad capacitor C1 in parallel with the 10-kilohm load resistor of the positive half-wave rectifier circuit. Reconnect the meter to the output of the circuit (banded end of diode D1). Switch the Trainer ON and observe the DC voltage reading on the meter. Record the voltage reading below. Turn the Trainer off and remove the white jumper at J1.

E_{out} (DC) = ____________ volts

11. Remove the jumper wire at J1 and install it at J2. This places 100-microfarad capacitor C1 in parallel with the 10-kilohm load resistor of the negative half-wave rectifier circuit. Reconnect the meter to the output of the circuit (unbanded end of diode D3). Switch the Trainer on and observe the DC voltage reading on the meter. Record the voltage reading below. Turn the Trainer off and remove the white jumper wire.

E_{out} (–DC) = ____________ volts

Discussion

In step 7, you should have recorded zero volts DC as the AC waveform varies above and below zero by the same amount. The voltages are equal and opposite thus cancelling each other. In step 8 you should have measured a positive DC voltage because the negative portion of the waveform was clipped at approximately zero.

In step 9, you saw that the polarity of the output voltage could be changed by simply reversing the diode in the circuit. Note that D3 is installed in the opposite direction of D1. This causes clipping to occur on the positive half cycle of the input. You also noticed that the DC input was zero. This is for the same reason as in the positive half-wave rectifier circuit. The voltages are equal and opposite thus cancelling each other. And, the output measured a negative DC voltage because the positive portion of the waveform was clipped at approximately zero.

Next, in step 10, you installed a capacitor in parallel with the load resistor of the positive rectifier circuit. You should note that C1 is an electrolytic type capacitor and is polarity sensitive. You should have measured an increased positive DC voltage that agreed with the peak AC value measured earlier. The capacitor charges quickly to the peak value, then discharges during the nonconducting half cycle of the diode. Since the discharge time is much greater than the half-cycle time, you did not see any appreciable voltage decay. The voltage appeared to be pure DC. In step 11 you did the same for the negative half-wave rectifier. Note that filter capacitor C2 is installed reversed that of C1 because this is a negative rectifier circuit.

Procedure (Cont.)

12. Use a second violet jumper wire to obtain the circuit shown in Figure E4-4. Install it between the bottom 15 VAC terminal block in the LINE FREQ section of the Trainer and the other terminal end onto the VAC2 terminal in Block 4. Do NOT use any test equipment except the Trainer's meter set to measure +DC voltage in this step. Connect the meter across the output of the circuit. Turn the Trainer ON and record the meter reading below. Switch the Trainer OFF.

_____________ +DC volts

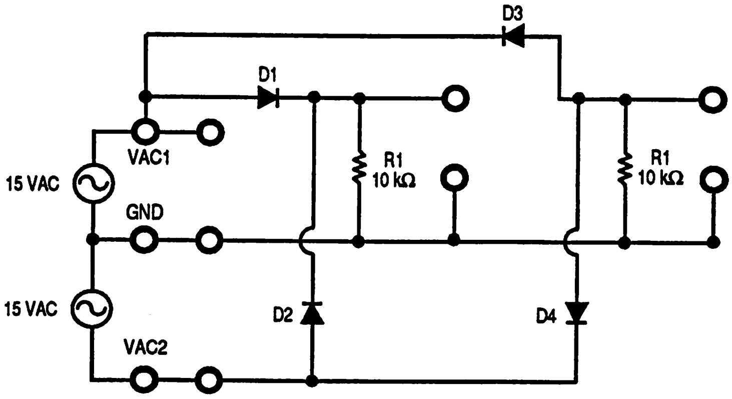


Figure E4-4
Full-wave positive rectifier.

13. Connect the Y1 probe to one of the inputs and Y2 to the output across R1. Switch the Trainer ON. Draw the input waveform in the space provided in Figure E4-5A. Also draw the output waveform in the space provided in Figure E4-5B. Switch the Trainer OFF.

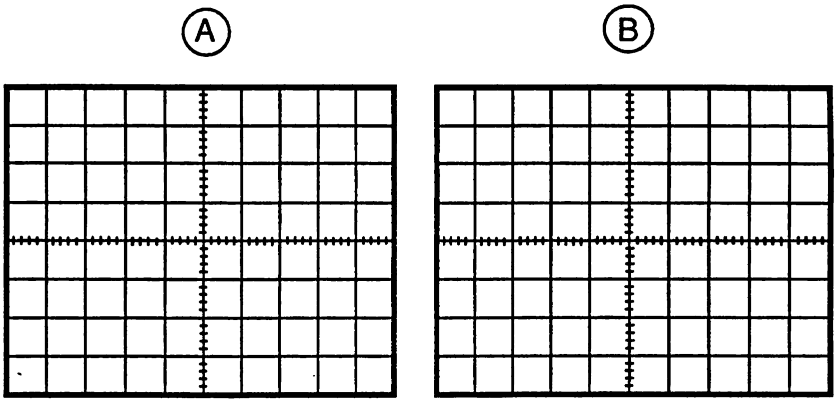


Figure E4-5
Waveforms for the full wave rectifier.

14. With the Y1 probe still connected to one of the inputs, connect Y2 and the meter to the output across R2. Switch the Trainer ON. Observe the input and output waveform. Switch the Trainer OFF.

15. With the Trainer switched off, connect the 100 microfarad capacitor (C1) into the positive full-wave rectifier circuit by installing a white jumper wire at J1. Reconnect the Y2 scope probe and the meter to the output across R1. Switch the Trainer ON and observe the oscilloscope presentation and the meter reading. In the following statements, underline what you observed. Then switch the Trainer OFF.

    Oscilloscope display changed to (pulsating DC/AC/pure DC).

    Meter measurement (increased/decreased/stayed the same).

16. Now connect a 100 microfarad capacitor (C2) into the negative full-wave rectifier circuit. Move the white jumper wire from J1 to J2. Connect the Y2 scope probe and the meter to the output across R2. Switch the Trainer ON and observe the oscilloscope presentation and the meter reading. In the following statements, underline what you observed. Then switch the Trainer OFF.

    Oscilloscope display changed to (pulsating DC/AC/pure DC).

    Meter measurement (increased/decreased/stayed the same).

Discussion

In step 12, you constructed a positive full-wave rectifier. It has a positive output because of the positioning of the diodes in the circuit. The diodes pass the positive pulses to the output and clip or block the negative pulses. The output voltage is positive DC and has a value of equal to $0.636 \times E_{peak}$. The important point to remember is that a center tapped transformer is used, and thus, the input voltage at any given time is 15 VAC. The maximum AC voltage that either diode sees is only 15 volts. When the top of the transformer goes positive, D1 conducts. At the same time D2 sees the negative voltage at the bottom of the transformer's secondary and it cuts off. When the bottom of the transformer goes positive D2 conducts and D1 is cut off. In this way, only positive pulses are coupled through the alternately conducting diodes to the output. Therefore, for each cycle of the input (time of 16.67 ms) two pulses appear in the output (16.67 ms/ 2). The time of one pulse in the output is 8.34 ms which converts to a frequency of 120 Hz (1/8.34 ms).

In step 14, you checked the output of a negative full-wave rectifier. The only difference in the output is a negative voltage. This voltage is determined by the positioning of the diodes in the circuit. As you can see, the diodes are reversed from the previous full-wave rectifier circuit.

When the capacitor is connected in parallel with the load resistor, it charges to the peak of the output pulses and holds the output to a DC voltage that is close to the peak value. This effectively changes (filters) the pulses and provides an almost pure DC output.

By checking the output of the negative full-wave rectifier, you found that the Trainer's digital meter measured a –DC voltage. The voltage values were the same as that in the positive full-wave circuit, only in a negative direction. Notice also that the filter capacitor C2 is reversed.

Procedure (Cont.)

17. Install a white jumper wire at J1 and another white jumper wire at J2. Connect your meter (set to measure DC voltage) between V_1 and V_2 in Block 4. What voltage would you expect?

______ volts DC

Switch the Trainer ON and verify your conclusion. Then switch the Trainer OFF and remove all jumper wires and test leads. Then read the following discussion.

Discussion

By connecting the meter across both circuits you should have measured the sum of the individual outputs—approximately 40 volts. This new circuit is a positive and negative full wave rectifier. It is a commonly found configuration that supplies both positive and negative voltages to a circuit.

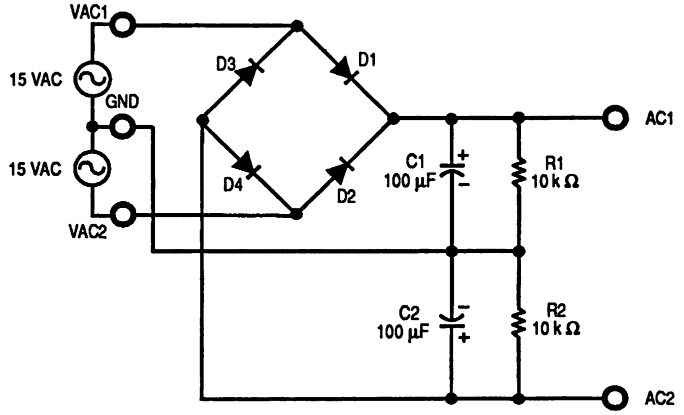


Figure E4-6
Positive and negative full wave rectifier.

Summary

In the first part of this experiment, you used a single diode (a half-wave rectifier) to change an AC waveform into pulsating pulses. You saw how the diode acted as a switch to pass a positive cycle of AC while blocking its negative half. The half-wave rectifier provides current flow for only 50% of the input signal. In addition, you calculated the input frequency and found it to be the same as the output frequency. You also saw that with the addition of a capacitor in parallel with the load resistor the rectified pulses from the half-wave rectifier can be converted to an almost pure DC.

In the second part of this experiment, you constructed a full-wave rectifier using two diodes, both placed in the same direction facing the transformer. In this circuit, current flows for almost 100% of the input signal. Again, by adding a capacitor in parallel with the load resistor, an almost pure DC voltage is obtained.

In the last part of the experiment, you combined two full wave rectifiers, positive and negative, into a single ± power supply.

Experiment 5
Zener Diodes

Purpose

1. To measure some of the characteristics of a zener diode.
2. To verify its application as a voltage regulator.

Introduction

Experiment 5 is located in Block 5 in the upper middle of Circuit Board #1 as shown in Figure E5-1. All jumper locations mentioned in this experiment will refer to this block or to the Circuit Board's Interface Panel.

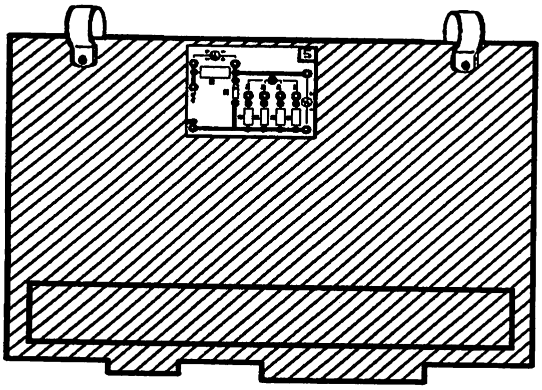


Figure E5-1
Block 5 of Circuit Board #1.

In this experiment you will demonstrate the operational characteristics of a typical low power zener diode. You will measure its performance under forward and reverse bias conditions. Then you will use this diode in a voltage regulator circuit. You will demonstrate the ability of the circuit to compensate for input voltage and output load variations. Read the entire procedure before performing this experiment.

Material Required

1 ETW-3600 Analog Trainer
1 ETW-3567 Accessory Backpack
1 ETB-6103
    1 Board #1
    1 Red jumper wire
    1 Black jumper wire
    1 White jumper wire

Procedure

1. With the Trainer turned off, install Circuit Board #1. Make sure all Trainer controls are turned fully counterclockwise. Also make sure that Board #1 is switched off.

2. Construct the circuit shown in Figure E5-2 using the red and black jumper wires—red for + voltage and black for ground. Looking at the zener diode in the circuit in Figure E5-2, the zener diode is ____________________ (forward biased/reverse biased).

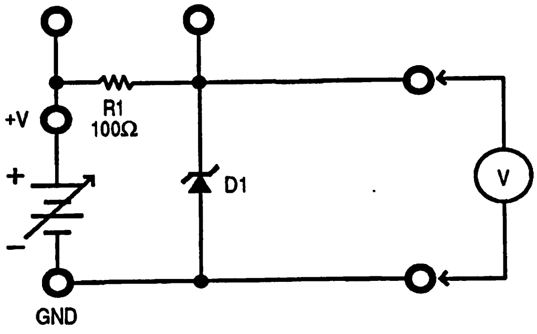


Figure E5-2
Circuit for Experiment 5.

3. Set up the Trainer's multimeter to measure DC voltage under 20 volts. Then connect the meter leads across the zener diode (V_2) as shown in Figure E5-2. Turn on your Trainer.

4. Switch Board #1 ON. Now adjust the Trainer's +DC power supply control slowly clockwise and observe the increase in voltage across the zener diode as indicated on your meter. Continue turning the +DC control until the voltage across the diode stops increasing at a rapid rate and effectively remains constant. At this point, stop turning the +DC control and, as accurately as you can, measure the voltage across the zener diode. Record this voltage in the DIODE VOLTAGE column (upper space) of the table shown in Figure E5-3. Switch Board #1 OFF.

DIODE VOLTAGE	DIODE CURRENT	INPUT VOLTAGE

Figure E5-3
Record for the zener regulator's voltage and current.

5. Next, move the meter test leads to measure the voltage across R1. Switch Board #1 ON and measure the voltage. Then use the voltage across R1 and the resistance of R1 (100 ohms) to calculate the current flowing in the circuit ($I = E/R = E_{R1}/100\ \Omega$). Your calculated value of current represents the amount of current that is now flowing through resistor R1 and the zener diode. Record this current in the DIODE CURRENT column (upper space) in Figure E5-3. Switch Board #1 OFF.

6. Move your meter test leads to measure input voltage (V_{in}) across +V and GND. Switch Board #1 ON and record this value in the INPUT VOLTAGE column (upper space) of the table shown in Figure E5-3. Switch Board #1 OFF.

7. Now you will make several voltage measurements which must be performed quickly to avoid overheating the diode. First measure the voltage across the zener as you turn the +DC control fully clockwise. Measure the voltage across the diode and record this voltage in the DIODE VOLTAGE column (lower space) of the table shown in Figure E5-3. Next, measure the input voltage and record this value in Figure E5-3. Now measure the voltage dropped across R1. The voltage across R1 is now equal to:

_______ volts.

8. Use the voltage across R1 (recorded in step 7) and the resistance of R1 to calculate the current flowing through R1. This calculated value of current represents the current that flows through R1 and the zener diode. Record this current in the DIODE CURRENT column (lower space) in Figure E5-3.

9. Turn off Board #1. Then read the following discussion.

Discussion

In this part of the experiment, you subjected the zener diode to a variable reverse voltage, and recorded the voltage across the zener and the resulting current through the zener at two important points. The diode was **reverse biased** since its cathode was positive with respect to its anode.

The first diode voltage and current values that you recorded in the upper row of Figure E5-3 represent the point where the diode first enters the zener breakdown region. At this time, the zener voltage levels off at an almost constant value and the current just begins to increase at a rapid rate. You should have found that the diode voltage leveled off at a value of approximately 4.3 volts. This is the diode's zener voltage rating. However, you may have measured a voltage that was several tenths of a volt higher or lower than this value because the diode has a zener voltage tolerance of ±10 percent. The current that you recorded should be quite low, since it represents the current through the diode just after the breakdown point is reached. You probably recorded a current that was between 2 and 5 milliamperes. The input voltage at this time should have been approximately 4.5 to 5 volts.

Next, you set the input voltage to its maximum value. At this time, the current flowing through R1 and the zener diode was much higher. As you increased the input voltage you should have found that the voltage across the zener increased only slightly (perhaps only one or two tenths of a volt). The diode voltages that you recorded in Figure E5-3 should, therefore, be very close to one another. However, the diode current that you recorded for maximum input voltage should be much higher than the current that you measured initially. You should have obtained a diode current that was between 80 and 100 milliamperes. At this point, the zener is operating at the limit of its power dissipation rating. The input voltage at this time should have been about 15 volts.

A direct comparison of the diode currents and voltages in Figure E5-3 should show that the zener voltage changes only slightly while the current varies over a wide range when the diode is operating within its zener region. Comparing the input and zener voltages, you can see that as the input voltage varies, the zener voltage varies only a few tenths of a volt. This clearly demonstrates the value of the zener in compensating for input voltage variations.

If the zener diode leads were reversed, this would cause the zener to be forward biased. When forward biased, the zener acts as any ordinary PN junction diode. In this case, you would measure a forward drop in the 0.6 to 0.7 volt range.

Procedure (Cont.)

10. In the next part of this experiment, a regulated output voltage of 4.5 volts is supplied to various resistive loads. When a load resistor is connected across the zener diode, the circuit effectively becomes a simple shunt voltage regulator circuit. Your experimental circuit should be capable of operating with input voltages between 9 and 12 volts and the output load currents between 0 and 30 milliamperes. You will test this circuit by setting the input voltage to 12 volts and observe the regulated output voltage for various load currents.

11. Connect the Trainer's meter test leads across the input to measure the input voltage. Switch Board #1 ON and adjust the Trainer's +DC voltage control until the meter indicates that the voltage is 12 volts. Switch Board #1 OFF.

12. Now connect the meter test leads across zener diode D1. With no load resistor connected across the zener diode (no load current), switch Board #1 ON and measure the voltage across D1. Record the measured voltage in the OUTPUT VOLTAGE column of the table shown in Figure E5-4. Switch Board #1 OFF.

13. Install a white jumper wire at J1. This connects a 1000 ohm resistor (R2) across diode D1. This resistor will serve as a load with a current of approximately 4.5 milliamperes at the rated output voltage of 4.5 volts. Switch Board #1 ON and measure the output voltage across D1. Record the measured voltage in the appropriate space in the OUTPUT VOLTAGE column of the table shown in Figure E5-4.

14. Repeat step 14 using load resistors with values of 470 ohms, 220 ohms, and 47 ohms by moving the white jumper wire from J1, to J2, J3, and then to J4. These resistors will draw load currents of approximately 9.6, 20, and 96 milliamperes, respectively, assuming the output voltage remains at 4.5 volts. After you connect each load resistor across D1 and measure the voltage developed across the zener diode, record the measured voltage in the space provided in Figure E5-4. Turn off Board #1. Return to the table in Figure E5-4 and explain any unusual variations in the output voltages listed.

LOAD RESISTANCE (OHMS)	APPROXIMATE LOAD CURRENT (MILLIAMPERES)	OUTPUT VOLTAGE (VOLTS)
OPEN (NO LOAD)	0	
1000	4.5	
470	9.6	
220	20	
47	96	

Figure E5-4
Record for output voltage of regulator over a range of output loads.

15. Reinstall the jumper wire at J1. Switch Board #1 ON. With the voltmeter still connected across the zener diode, monitor the output while varying the Trainer's +DC voltage control. Notice that the output voltage remains relatively constant until the DC voltage falls below 10 volts. Turn Board #1 and the Trainer off, and remove all jumper wires.

Discussion

In this part of the experiment, you demonstrated the zener diode's ability to provide a regulated output voltage under various load conditions. You connected different resistors to the output of the regulator circuit to draw specific amounts of load current from the circuit. You also measured the output voltage in each case. You should have obtained an output voltage of approximately 4.5 volts (±10 percent) across the zener diode. This voltage should have remained essentially constant when the output was open (no load) as well as when the 1000 ohms, 470 ohms, and 220 ohm resistors were connected to the circuit. However, the output voltage should have dropped well below 4.5 volts when the 47 ohm load resistor was connected to the circuit. You probably measured a voltage of about 3 volts, or less. This decrease in output voltage should result because the 47 ohm resistor draws a load current of 96 milliamperes, at an output voltage of 4.5 volts. This situation cannot occur because the 12 volt source and 100 Ω resistor cannot supply 96 mA into a 47 ohm load.

Actually, when the 47 ohm load is connected, the current through the zener regulator decreases, and the load current increases proportionally. As long as the zener current remains high enough, the zener will continue to operate in its breakdown region and provide a relatively constant load voltage. If the load resistance becomes too low and attempts to draw more current from the circuit than the series resistor will permit, the zener current drops to near zero. In effect, the low load resistance draws all of the available current. The effect is the same as if the zener was removed from the circuit. In this case the equivalent circuit simply becomes a voltage divider made up of the 100 ohm series resistor and the 47 ohm load. The resulting output voltage is determined by the voltage divider ratio of the two resistors and the input voltage. This illustrates that **the zener regulator is designed for a specific set of load conditions** and if these conditions are exceeded, improper operation will result.

Summary

As you have learned in the textbook, zener diodes are specially constructed to operate at voltages that equal or exceed their breakdown voltage ratings. Zeners are most widely used in applications where it is reversed-biased to operate constantly within its breakdown region. Under these conditions, the zener diode is effectively used to provide voltage regulation.

In the first part of this experiment, you subjected the zener diode to various reverse voltages. A direct comparison of the diode currents and voltages showed that the zener voltage changed only slightly while the current varied over a wide range. This clearly demonstrates the value of the zener in compensating for input voltage variations.

In the second part of the experiment, you demonstrated the zener diode's ability to provide a regulated output voltage under various load conditions. You connected different resistors to the output of the regulator circuit to draw specific amounts of load current from the circuit. From your results, you saw that the output remained at the zener's voltage until the maximum load current was exceeded.

As a regulator, the zener diode is able to maintain a relatively constant output voltage even though changes in input voltage and output current occur.

Experiment 6
Testing Bipolar Transistors

Purpose

1. To learn how to test NPN and PNP bipolar transistors.
2. To identify an unknown bipolar transistor as either an NPN or PNP type.
3. To identify a transistor's base lead using an ohmmeter.

Introduction

Experiment 6 is located in Block 6 in the middle of Circuit Board #1 as shown in Figure E6-1. All jumper locations mentioned in this experiment will refer to this block or to the Circuit Board's Interface Panel.

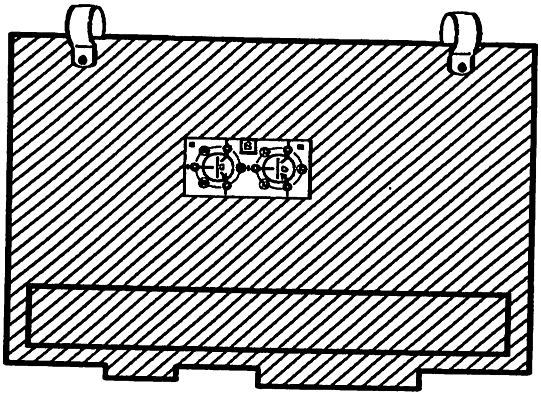


Figure E6-1
Block 6 of Circuit Board #1.

In this experiment, you will use the converter circuit on the Interface Panel and the Trainer's meter to test an NPN and PNP transistor. You will also be able to establish if an unknown bipolar transistor is an NPN or PNP type and which is its base lead.

Material Required

- 1 ETW-3600 Analog Trainer
- 1 ETW-3567 Accessory Backpack
- 1 ETB-6103
    - 1 Board #1
    - 1 Red jumper wire
    - 1 Black jumper wire

NOTE: Many digital and electronic meters now provide a diode check mode, indicated by a diode symbol. In this mode, a constant current source instead of a constant voltage source is sometimes provided. A silicon diode will indicate between 0.5 and 0.7 V_F. A germanium diode should indicate between 0.2 and 0.4 V_F. In some cases, a diode is indicated, but the meter will measure ohms. This meter position is designed to measure the forward and reverse resistances of a diode. If you are not sure how the function on your meter works, check the meter's owner manual.

Procedure

1. Locate the NPN transistor (Q1) in Block 6 of Circuit Board #1 and examine it closely. Compare the transistor and its labelled leads to that shown in Figure E6-2A. The transistor's emitter (E) lead will be to the left, the base (B) lead will be in the middle, and the collector (C) lead will be on the right side. Notice that an additional outline drawing of the transistor (as viewed from the bottom) is shown in Figure E6-2B. Manufacturers generally provide this type of outline drawing in the transistor's data sheet to help in identifying the transistor's emitter, base, and collector leads.

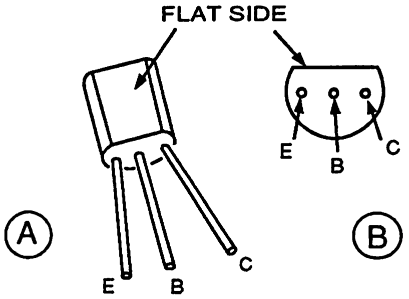


Figure E6-2
Locating the base, emitter, and collector leads of the NPN transistor (Q1).

2. Now you will use the converter circuit on the Interface Panel to measure the forward resistance of the transistor's emitter-base and collector-base junctions. First, make sure the Trainer is off and then install Board #1. Connect the multimeter (set to measure DC volts on the 2 V range) test leads to the converter output terminals. Red test lead connects to the +DC terminal and the black lead goes to the −DC terminal. Install a red jumper lead onto the converter's +Ω terminal and the black jumper lead onto the −Ω terminal. Set the converter's k/M switch on the Panel to the k (kilohm) position.

3. Connect the converter's red jumper lead to the transistor's base lead as shown in Figure E6-3A. Then alternately connect the converter's black jumper lead to the transistor's emitter and collector leads. Switch the Trainer and Board #1 ON. Note the forward resistance across each junction and record the two readings in the spaces provided in Figure E6-3B.. Notice that the positive test lead must be connected to the P-type base while the negative test lead is connected to the N-type emitter or collector.

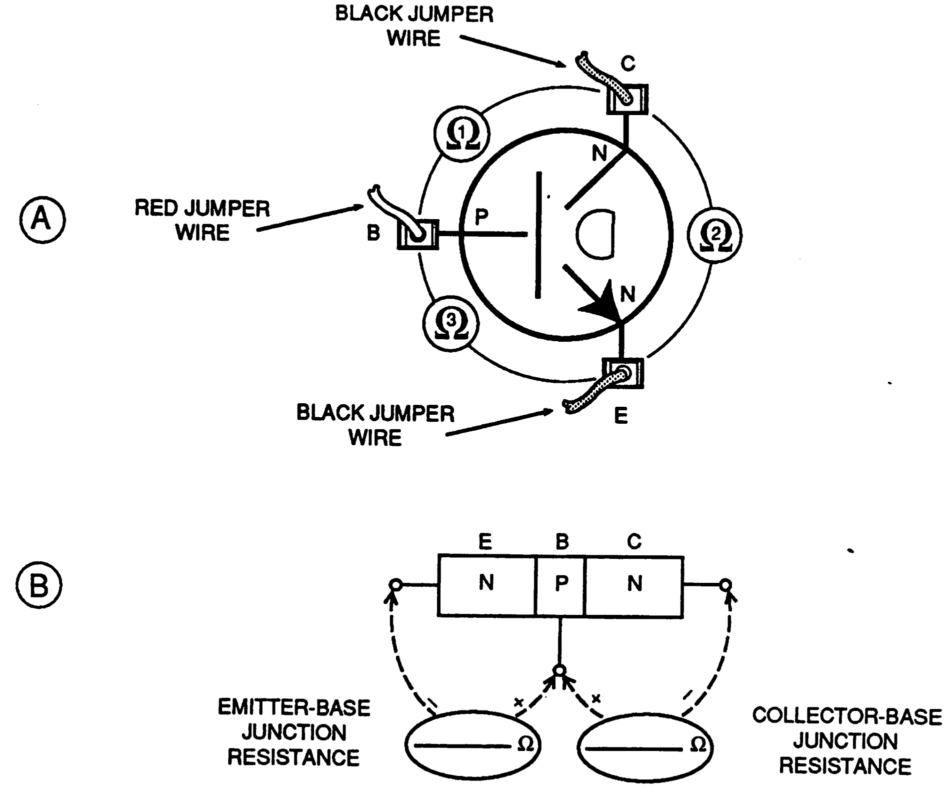


Figure E6-3
Checking the forward resistance of each junction in an NPN transistor.

4. Now, you will measure the reverse resistance of the transistor's emitter-base and collector-base junctions. Set the k/M switch on the Panel to the M position. This time connect the black jumper lead to the base, and alternately connect the positive test lead to the emitter and collector, as shown in Figure E6-4A. Note the reverse resistance across each junction and record your readings in the spaces provided in Figure E6-4B.

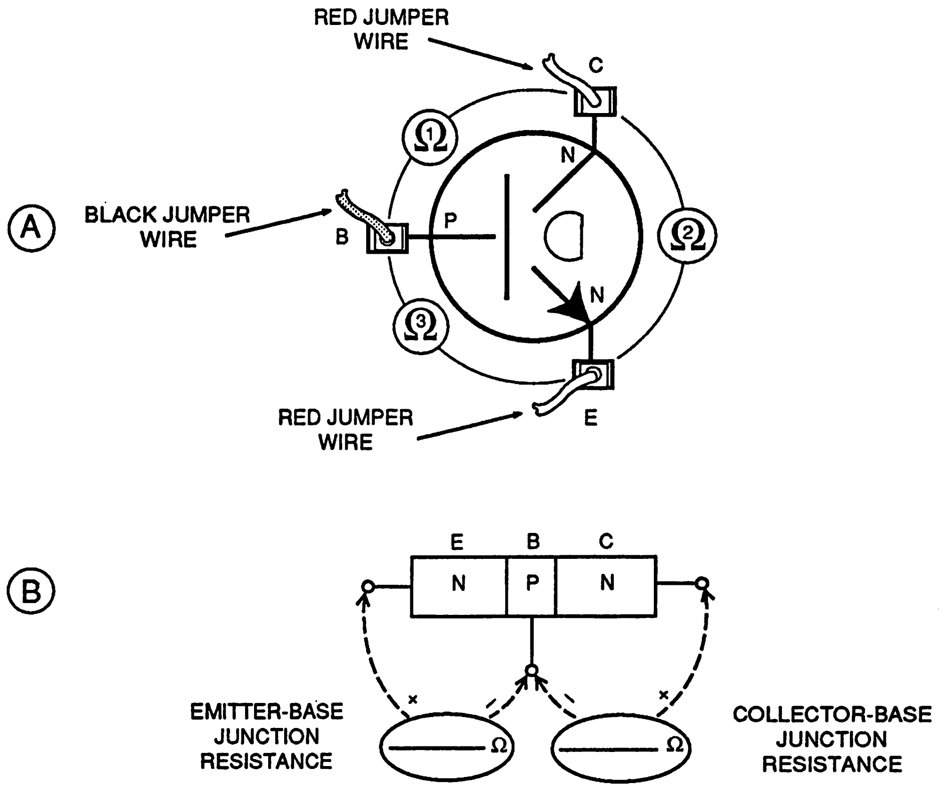


Figure E6-4
Checking the reverse resistance of each junction in an NPN transistor.

5. As a final check of this transistor, check the resistance in both directions between the emitter and collector leads of the transistor. Note the resistance reading with the red and black jumper wires in one direction and then again reversed.

Discussion

In this portion of the experiment, you measured the forward and reverse resistances across the emitter-base and collector-base junctions of an NPN transistor. You should have discovered that the forward resistance of each junction was much lower than the reverse resistance, thus, indicating that each junction is functioning like a PN junction diode. You probably measured a forward resistance of several hundred ohms, or more. Your actual readings may vary due to transistor manufacturing tolerances. However, your reverse resistance readings should have been extremely high (your meter probably indicated that the reverse resistance was infinite). The exact readings that you obtained are not as important as the difference between the two readings. One reading should be relatively low and the other very high if the transistor is functioning properly. Only when a particular junction has shorted or opened will it exhibit a very low or very high resistance in both directions. Since your NPN transistor is made from silicon, it will allow very little leakage current to flow through either junction when reverse-biased. This is why your reverse resistance readings were high. When you measured from emiter to collector or collector to emitter, the reading was always high. It was high because you were reading across two junctions, one of which was always reversed.

Procedure (Cont.)

6. Locate the PNP transistor (Q2) in Block 6. Notice the location of the emitter, base, and collector leads. The leads are identified in the outline drawing shown in Figure E6-5. From this drawing you can see that the base and collector leads are reversed from that of the NPN transistor. However, the leads of Q2 were rerouted on the circuit board to match the leads of Q1 for easier comparison of transistors.

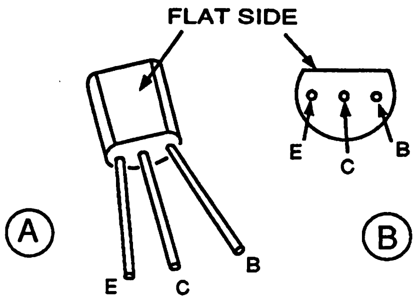


Figure E6-5
The PNP transistor.

7. Now you will measure the forward resistance of the transistor's emitter-base and collector-base junctions. Set the k/M switch on the Panel to the k position. Alternately connect the red and black jumper wires from the Panel's converter circuit as shown in Figure E6-6A and record your forward resistance readings in the spaces provided in Figure E6-6B. Notice that the negative test lead must be connected to the N-type base while the positive test lead is connected to the P-type emitter or collector.

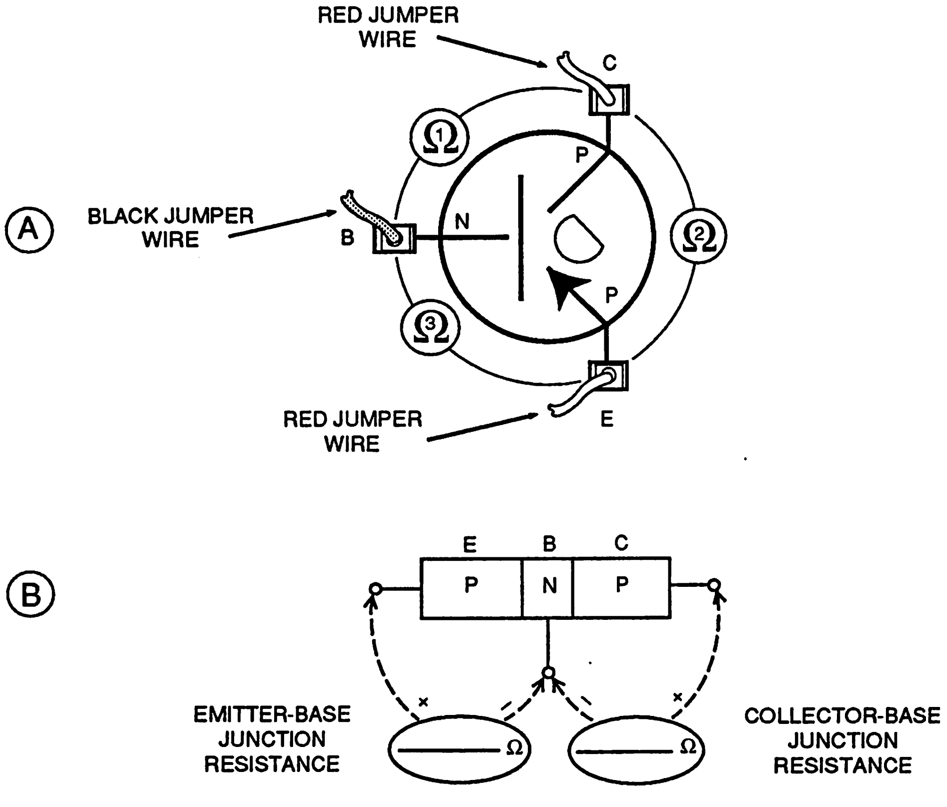


Figure E6-6
Circuit for testing the forward resistance of a PNP transistor.

8. Now measure the reverse resistance of the transistor's emitter-base and collector-base junctions. Set the k/M switch on the Panel to the M position. This time connect the red and black jumper wires as shown in Figure E6-7A. Record your reverse resistance readings in the spaces provided in Figure E6-7B.

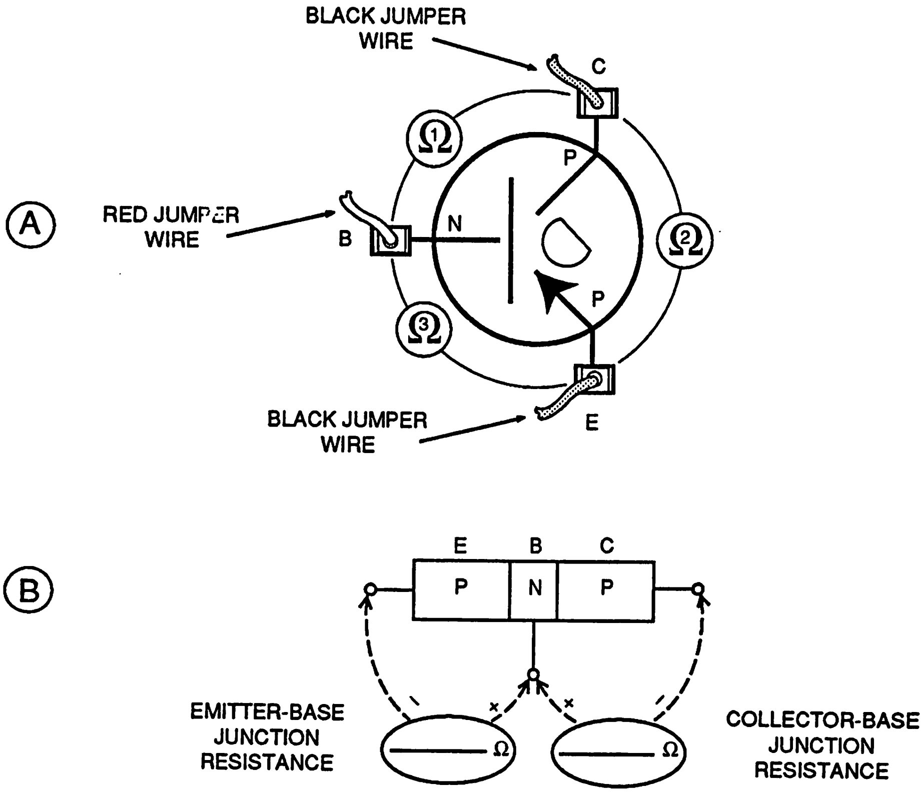


Figure E6-7
Circuit for testing the reverse
resistance of a PNP transistor.

9. As in step 5, check the resistance in both directions between the emitter and collector leads of the transistor. Note the resistance reading with the red and black jumper wires in one direction and then again in the other.

Discussion

In this portion of the experiment, you measured the forward and reverse resistances across the emitter-base and collector-base junctions of a PNP transistor. Your measurements should have been similar to the NPN transistor. If a germanium transistor had been tested, the readings would have been much lower. Germanium transistors always have a lower junction resistance then similar types made from silicon. And, just as with the NPN transistor, checking the resistance between the emitter and collector in both directions results in high readings.

Summary

In the first part of this experiment, you measured the forward and reverse resistances across the emitter-base and collector-base junctions of an NPN transistor. You discovered that the forward resistance of each junction was much lower than the reverse resistance. This is typical of a silicon transistor such as the one you checked.

In the second part of this experiment, you measured the forward and reverse resistances across the emitter-base and collector-base junctions of a PNP transistor. Your measurements should have been similar to the NPN transistor.

With the junction-resistance information obtained in this experiment, you can establish if an unknown transistor is either a PNP or an NPN. It is also possible to determine a transistor's base lead. With an ohmmeter, you can also test a transistor for shorted (the most common problem) or open junctions.

Experiment 7
Common-Emitter Amplifier Characteristics I

Purpose

1. To demonstrate the operation of a common-emitter amplifier.
2. To observe and measure some of its important electrical characteristics.

Introduction

Experiment 7 is located in Block 7 in the upper right of Circuit Board #1 as shown in Figure E7-1. All jumper locations mentioned in this experiment will refer to this block or to the Circuit Board's Interface Panel.

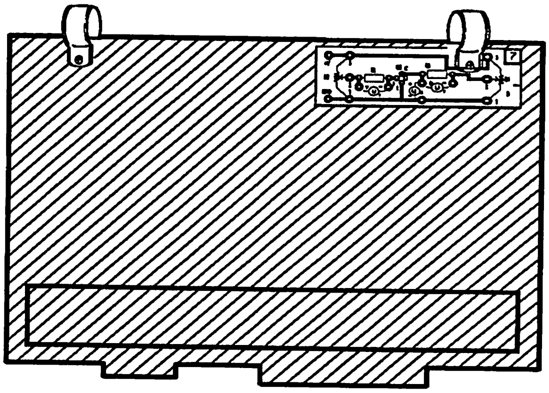


Figure E7-1
Block 7 of Circuit Board #1.

The common-emitter configuration is used more often than the common-base and common-collector configurations because it provides current, voltage, and power amplification. An understanding of the basic electrical characteristics of a common-emitter transistor is therefore very important.

In this experiment you will observe the relationship between a transistor's base current, collector current, and collector-to-emitter voltage. You will begin by taking measurements and then you will plot the transistor's collector characteristic curves. Next, you will use the curves to determine the current gain of the device. Read the entire procedure before performing this experiment.

Material Required

- 1 ETW-3600 Analog Trainer
- 1 ETW-3567 Accessory Backpack
- 1 ETB-6103
  - 1 Board #1
  - 1 Red jumper wire
  - 1 Black jumper wire
  - 3 Blue jumper wires
  - 3 Orange jumper wires

Procedure

1. With the Trainer turned off, install Circuit Board #1. Make sure that Board #1 is switched off. Refer to Figure E7-2 and construct the circuit in Block 7. Use the red jumper wire for +V and the black jumper wire for ground. Use the three orange jumper wires to connect the Trainer's 100 kilohm pot (potentiometer) at the Interface Panel (1, 2, and 3) to R1's terminals (1, 2, and 3) in the block. Finally, use the three blue wires to connect the Trainer's 1 kilohm pot at the Interface Panel (1, 2, and 3) to R4's terminals (1, 2, and 3) in the block.

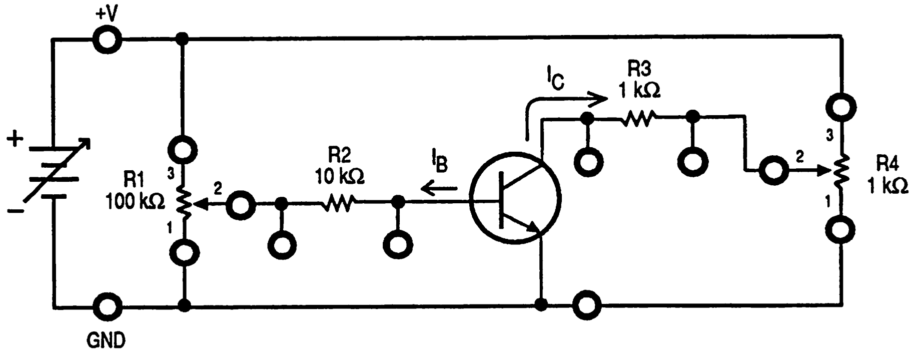


Figure E7-2
Circuit for Experiment 7.

4706.47

2. Set up the Backpack's multimeter to measure +DC voltage in the 20 V Range. Connect the meter test leads to measure the voltage across R2 (V_{IB}). Turn potentiometer R1 (100kΩ) fully counterclockwise and set R4 (1kΩ) to mid-range.

3. Turn the Trainer and Board #1 ON. Adjust the Trainer's +DC voltage control fully clockwise. You will be using potentiometer R1 to control the base current (I_B) of the NPN transistor and potentiometer R4 to control the transistor's collector-to-emitter voltage (V_{CE}). Resistors R2 and R3 are used to limit the currents through the transistor to safe values. R2 and R3 also provide a way to measure the base and collector currents.

4. Now adjust the transistor's base current (I_B) to a value of 10 microamperes. To do this, you must turn potentiometer R1 slowly until the voltage across R2 (measure this voltage with your meter) is equal to 0.1 volt. According to Ohm's law, the current through R2 must now equal 0.1 volts divided by 10 kilohms, or 10 microamperes. Since this current also flows through the transistor's base, I_B must equal 10 microamperes at this time. The base current could have been measured with an ammeter, but that would require opening the current path and inserting an ammeter in series with R2 and the transistor's base.

5. Without disturbing the setting of R1 adjust potentiometer R4 until the transistor's emitter-to-collector voltage (V_{CE}) is equal to 1 volt.

6. Now measure the voltage across R3 (V_{IC}). Use this voltage measurement and the resistance of R3 (1000 ohms) to calculate the current flowing through R3 (V_{R3} divided by R3). Since R3 is connected to the transistor's collector lead, your calculated value of current also represents the collector current (I_C) flowing through the transistor. Record this value of I_C (in milliamperes) immediately below the V_{CE} value of 1 volt in the table provided in Figure E7-3.

I_B = 10 MICROAMPERES						
V_{CE} (VOLTS)	1	2	3	4	5	6
I_C (MILLIAMPERES)						

Figure E7-3

Record of I_C values from steps 4, 5, 6, and 7.

7. Complete the table in Figure E7-3 by adjusting V_{CE} to the remaining values indicated in Figure E7-3 and recording the corresponding values of I_C in the space provided. To do this simply repeat steps 5 and 6 for each of the remaining V_{CE} values in the table. When you complete the table in Figure E7-3 you will have a permanent record of I_C values over a range of V_{CE} values when I_B is held constant at 10 microamperes.

8. Now adjust the transistor's base current (I_B) to a value of 20 microamperes. To do this, simply turn potentiometer R1 slowly clockwise until the voltage across R2 (measure this voltage with your meter) is equal to 0.2 volts. This will cause I_B to have a value of 20 microamperes.

9. Without disturbing the setting of R1, adjust potentiometer R4 until the transistor's emitter-to-collector voltage (measure with your meter) is equal to 1 volt.

10. Use your meter to measure the voltage across R3. Then use Ohm's law (as you did in step 6) to calculate the current through R3. Your calculated current value represents the transistor's collector current (I_C) and should now be recorded (in milliamperes) immediately below the V_{CE} value of 1 volt in the table in Figure E7-4.

11. Complete the table in Figure E7-4 by adjusting V_{CE} to the remaining values indicated and recording the corresponding values of I_C. To do this, simply repeat step 10 for each value of V_{CE} indicated. Your completed table will show how I_C varies over a wide range of V_{CE} values when I_B is equal to 20 microamperes.

I_B = 20 MICROAMPERES						
V_{CE} (VOLTS)	1	2	3	4	5	6
I_C (MILLIAMPERES)						

Figure E7-4

Record of I_C values from steps 8, 9, 10, and 11.

12. Now adjust the transistor's base current (I_B) to a value of 30 microamperes. To do this, turn R1 clockwise until the voltage across R2 (measured with your meter) is equal to 0.3 volts. This will cause I_B to have a value of 30 microamperes.

13. Without disturbing R1, turn R4 clockwise until the transistor's emitter-collector voltage (measure with your meter) is equal to 1 volt.

14. Use your voltmeter to measure the voltage across R3. Then use Ohm's law (as you did in step 6) to calculate the current through R3. This current also represents the collector current (I_C) flowing through the transistor. Record this value of I_C (in milliamperes) below the V_{CE} value of 1 volt in the table in Figure E7-5.

I_B = 30 MICROAMPERES						
V_{CE} (VOLTS)	1	2	3	4	5	6
I_C (MILLIAMPERES)						

Figure E7-5

Record of I_C values from steps 12, 13, 14, and 15.

15. Complete the table in Figure E7-5 by adjusting V_{CE} to the remaining values indicated and recording the corresponding values of I_C. To do this, simply repeat step 14 for each value of V_{CE} indicated. Your completed table will show how I_C varies in relation to V_{CE} when I_B is equal to 30 microamperes. NOTE: Depending on transistor parameters, you may not be able to reach a V_{CE} of 6 volts.

16. Now use the corresponding values of I_C and V_{CE} that you recorded in Figure E7-3 to plot a collector characteristic curve on the graph shown in Figure E7-6. Simply plot the points where I_C and V_{CE} correspond as indicated in Figure E7-3. Connect those points to form a continuous curve and label the curve I_B = 10 microamperes.

17. Use the values of I_C and V_{CE} in Figure E7-4 to plot a second curve on the graph of Figure E7-6. Label this curve I_B = 20 microamperes. Use the values of I_C and V_{CE} in Figure E7-5 to plot another curve in Figure E7-6. Label this curve I_B = 30 microamperes.

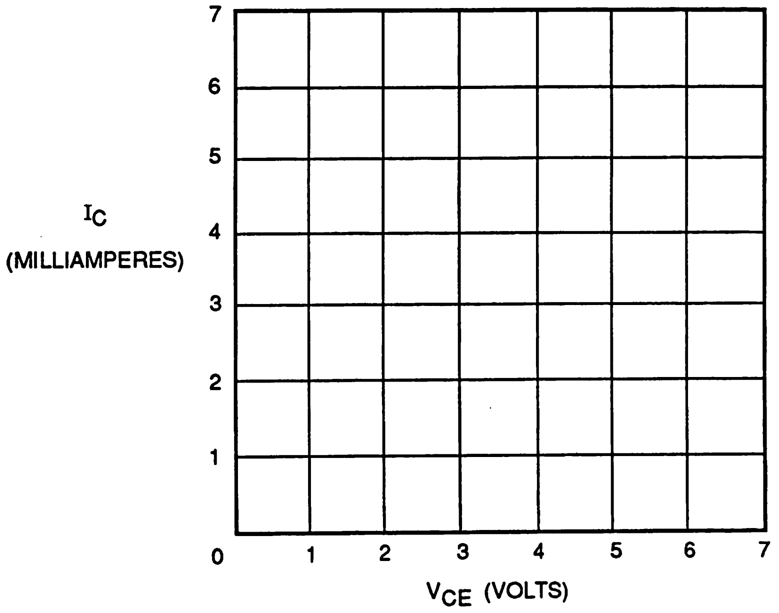


Figure E7-6
Graph for recording V_{CE} and I_C values.

18. Now use the set of collector characteristic curves that you just plotted to determine the beta of the transistor. First select a constant value of V_{CE} (above 4 volts). Then note the change that occurs in I_C when I_B changes by a specific amount. Use the equation for beta as shown below and record the beta of the transistor in the space provided:

$$\text{beta } (\beta) = \frac{\Delta I_C}{\Delta I_B}$$

beta (β) = ______

19. Use the beta value (β) that you obtained in the previous step to determine the transistor's alpha value (α). Simply use the conversion formula given below and record the transistor's alpha value in the space provided:

$$\text{alpha } (\alpha) = \frac{\beta}{\beta + 1}$$

alpha (α) = _______

20. Your experiment is now complete. Turn off Board #1 and your Trainer. Remove all jumper wires and then read the following discussion.

Discussion

In this experiment, you first observed the relationship between I_C, I_B, and V_{CE} in a common-emitter circuit configuration. You measured specific values of I_C over a range of V_{CE} values for several values of I_B. You then plotted these values to obtain a set of collector characteristic curves. The curves that you obtained should have the same general appearance as the ones shown in Figure 6-4 of the text. However, your curves were plotted for values of V_{CE} greater than 1 volt. Therefore, each curve does not show the initial rise in I_C but shows only the relationship between I_C and V_{CE} (for a specific I_B value) after I_C has leveled off (reached the knee of the curve). Each of your curves should, therefore, show that I_C remains almost constant as V_{CE} is increased. However, in each case the value of I_C should be much higher than the related I_B value for which the curve is plotted.

Next, you used your collector characteristic curves to determine the beta of the transistor. You probably obtained a beta that was greater than 100 and possibly as high as 200. This indicates that your transistor has a very high current gain. The exact value that you obtained is not important since beta values can vary over a wide range even for transistors of the same type. Remember, that the term beta represents the current gain for the common-emitter circuit configuration and it is always larger than 1.

Next, you used a conversion formula to calculate the transistor's alpha value. The alpha value that you obtained will be determined by the specific beta value that you derived earlier. However, due to the high gain of the transistor, the alpha value should be greater than 0.99. This means the transistor would have a current gain that is very close to 1, or unity when it is connected in a common-base configuration. Remember, that alpha represents the current gain for the common-base circuit configuration and it is always less than 1.

Summary

In the common-emitter amplifier, the emitter is common to both the input and to the output. The common-emitter configuration is used more often than either the common-base or the common-collector because it provides current, voltage, and power amplification. In this experiment you observed the relationship between a transistor's base current, collector current, and collector-to-emitter voltage. You measured and then plotted the transistor's collector characteristic curves. You saw that I_C remains almost constant as V_{CE} is increased. However, you found that I_C was much higher than the related I_B value for which the curve was plotted.

In the final part of the experiment, you used those curves to determine the current gain (beta) of the transistor. You obtained a beta that was greater than 100 indicating that your transistor has a very high current gain. Next, you calculated the transistor's alpha value which is always less than 1.

Experiment 8
Common-Base Amplifier Characteristics

Purpose

1. To apply a sine wave signal to a common-base amplifier and measure some of its important electrical characteristics.
2. To compare the input signal to the output signal both in phase and amplitude.

Introduction

Experiment 8 is located in Block 8 on the right side of Circuit Board #1 as shown in Figure E8-1. All jumper locations mentioned in this experiment will refer to this block or to the Circuit Board's Interface Panel.

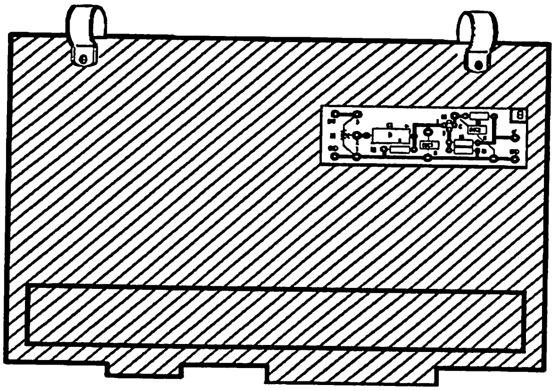


Figure E8-1
Block 8 of Circuit Board #1.

The common-base configuration is not used as frequently as the common-emitter and common-collector configurations. However, it has characteristics that make it useful in certain applications. Therefore, it is important to understand the characteristics of this circuit configuration. In this experiment, you will construct a simple common-base amplifier circuit and apply a signal to the emitter of the transistor. You will observe both the input and output waveforms and note their phase relationship. You will also calculate the voltage gain of the amplifier circuit.

Material Required

1 ETW-3600 Analog Trainer
1 ETW-3567 Accessory Backpack
1 ETB-6103
    1 Board #1
    1 Red jumper wire
    1 Black jumper wire
    3 Orange jumper wires
    1 Blue jumper wire
1 Dual-trace oscilloscope

Procedure

1. With the Trainer turned off, install Circuit Board #1. Make sure that Board #1 is OFF. Also make sure all Trainer controls are turned fully counterclockwise.

2. Refer to Figure E8-2 and install the proper jumper wires to construct the circuit. First, use the red and black jumper wires to connect the Panel +DC and GND terminals to the blocks +V and GND terminals. Then use the three orange jumper wires to connect the Panel's 100 kΩ terminals to the terminals of R1 in the block. Finally, use the blue jumper wire to connect the Panel's SINE terminal to the SINE terminal in the block.

   In this circuit, R2 and R4 serve as the collector and emitter loads. R3 and R5 set the base voltage or bias for the transistor. C1 couples the signal from the sinewave generator to the emitter of the transistor.

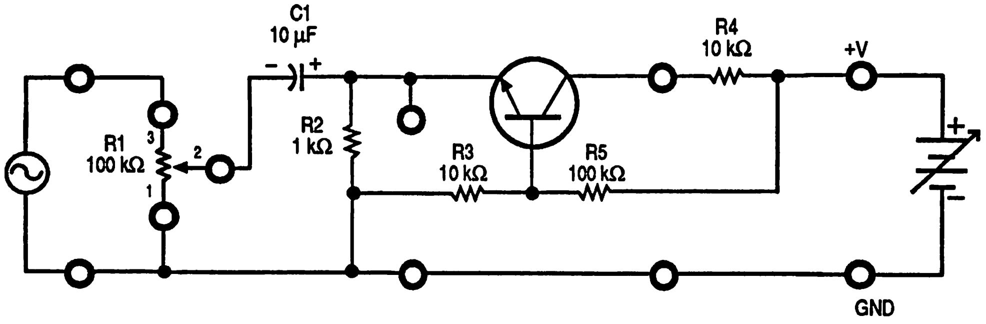


Figure E8-2
Circuit for Experiment 8.

3. Set the Trainer's generator frequency control to 200 Hz and the range switch to ×1.

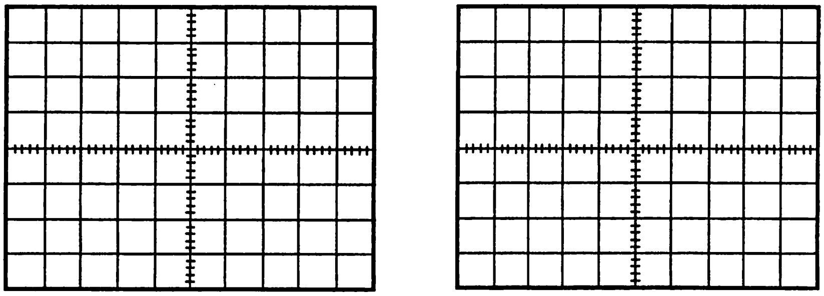
4. On the oscilloscope, set the TIME/CM to 1 ms/div. Also set the Y1 VOLTS/CM switch to the 0.05 V/div position and the Y2 VOLTS/CM switch to the 5 V/div position.

5. Connect the test lead from Y1 of your oscilloscope to the transistor emitter lead (OSC1) and the ground clip lead to GND.

6. Switch the power to the Trainer to ON and then Board #1 ON. Adjust the Trainer's + voltage control fully clockwise.

7. Observe the input signal. Then adjust the 100 kilohm potentiometer for a 0.05 $V_{P\text{-}P}$ signal. Record the waveform and its amplitude, in volts, in Figure E8-3A. Switch Board #1 OFF.

8. Connect the Y2 channel test lead to the collector and the ground clip lead to GND. Switch Board #1 ON and view the output signal on channel Y2. Are the two signals in phase? ______ (yes/no). Record the signal amplitude and waveform in Figure E8-3B.



Ⓐ INPUT SIGNAL (E_{in}) = ________ V_{p-p}
0.05 V/CM 1 mS/CM

Ⓑ OUTPUT SIGNAL (E_{out}) = ______ V_{p-p}
5 V/CM 1 mS/CM

Figure E8-3
Record of the common base waveforms.

9. Using the value of E_{in} in Figure E8-3A and E_{out} in Figure E8-3B, calculate the voltage gain of the circuit, using the formula:

$$\text{Voltage Gain } (A_V) = E_{out}/E_{in}$$

$$A_V = \_\_\_\_\_\_\_$$

Gain is not measured in any specific unit. Gain expresses the ratio of the output signal amplitude to the input signal amplitude.

10. This completes the experiment. Turn off the Trainer and Board #1. Remove all the jumper wires and proceed to the discussion.

Discussion

In this experiment, you applied a test AC signal to a common-base amplifier circuit. This closely simulates the operation of the common-base circuit in a piece of electronic equipment. You observed the input and output waveforms and their amplitude and phase relationships. You noticed that the amplitude of the output signal was larger than that of the input and that the output and input signals were in phase. In addition, you calculated the voltage gain of the circuit and noted that it is capable of providing voltage amplification.

Summary

In the common-base circuit, the input signal is applied to the emitter. This varies the forward-bias voltage across the base-emitter junction. The output of the circuit is taken from the collector and developed through the load. The magnitude of the output voltage is directly proportional to the amount of collector current flowing through the load. A small change in input voltage, regardless of whether this change is an increase or a decrease, causes a large change in output voltage

Experiment 9
Common-Emitter Amplifier Characteristics II

Purpose

1. To apply a sine wave signal to a common-emitter transistor amplifier and measure some of its important characteristics.

2. To compare the input signal to the output signal in terms of amplitude and phase relationship.

Introduction

Experiment 9 is located in Block 9 on the right side of Circuit Board #1 as shown in Figure E9-1. All jumper locations mentioned in this experiment will refer to this block or to the Circuit Board's Interface Panel.

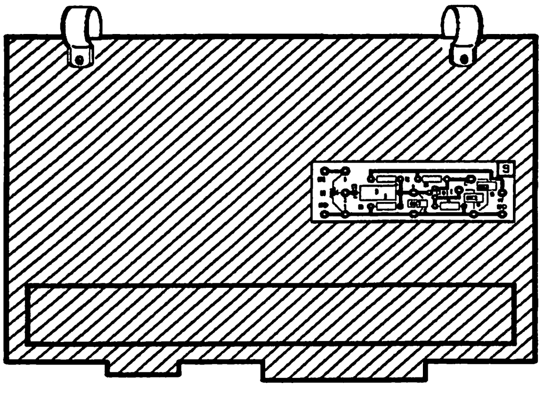


Figure E9-1
Block 9 of Circuit Board #1.

The common-emitter transistor configuration has many characteristics that make it useful for a variety of applications. As a result, it is the most widely used of the three basic transistor configurations. In this experiment, you will construct a common emitter amplifier circuit and apply an AC signal. You will then subject the circuit to several tests and calculate the voltage gain. You will also compare the input signal to the output to determine if this circuit configuration can provide polarity or phase inversion.

Material Required

1 ETW-3600 Analog Trainer
1 ETW-3567 Accessory Backpack
1 ETB-6103
    1 Board #1
    1 Red jumper wire
    1 Black jumper wire
    3 Orange jumper wires
    1 Blue jumper wire
1 Dual-trace oscilloscope

Procedure

1. With the Trainer turned off, install Circuit Board #1. Make sure that Board #1 is OFF. Also make sure all Trainer controls are turned fully counterclockwise.

2. Refer to Figure E9-2. Install the red and black jumper wires to connect the Panel's +DC and GND terminals to the block's +V and GND terminals. Then use the three orange jumper wires to connect the Panel's 100 kΩ terminals to the terminals of R1 in the block. Finally, use the blue jumper wire to connect the Panel's SINE terminal to the SINE terminal in the block.

   In this circuit, R4 and R5 are the collector and emitter loads. R2 and R3 set the bias for the transistor. C1 couples the signal from the sinewave generator to the base of the transistor.

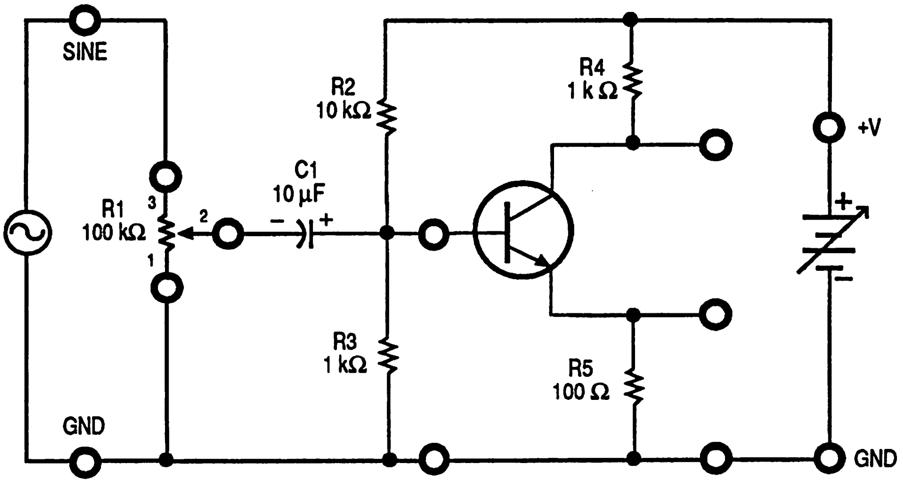


Figure 9-2
Circuit for Experiment 9.

3. Set the Trainer's generator frequency control to 200 Hz and set the range switch to the ×1 position.

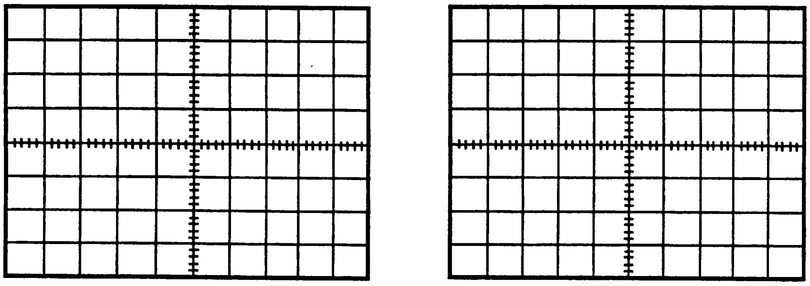
4. On the oscilloscope, set the TIME/CM to 1 ms/div. Also set the Y1 VOLTS/CM switch to the 0.5 V/div position and the Y2 VOLTS/CM switch to the 1 V/div position.

5. Connect the test lead from Y1 of your oscilloscope to the transistor base lead (OSC1) and the ground clip lead to GND.

6. First switch the Trainer and then Board #1 ON. Adjust the Trainer's + DC voltage control fully clockwise.

7. Observe the input signal. Then adjust the 100 kilohm potentiometer for a 0.5 $V_{P\text{-}P}$ signal. Record the waveform and its amplitude, in volts, in Figure E9-3A. Switch Board #1 OFF.

8. Connect the Y2 scope lead to the collector and the ground clip lead to GND. Switch Board #1 ON and view the output signal on channel Y2. Are the two signals in phase? ______ (yes/no). Record the signal amplitude and waveform in Figure E8-3B.



Ⓐ INPUT SIGNAL (E$_{in}$) = ______ V$_{p-p}$
0.5 V/CM 1 mS/CM

Ⓑ OUTPUT SIGNAL (E$_{out}$) = ______ V$_{p-p}$
1 V/CM 1 mS/CM

Figure E9-3
Record of the common emitter waveforms.

9. Using the value of E_{in} in Figure E9-3A and E_{out} in Figure E9-3B, calculate the voltage gain of the circuit.

$$\text{Voltage Gain } (A_V) = E_{out}/E_{in}$$

A_V = ______

10. This completes the experiment. Turn off the Trainer and Board #1. Remove all the jumper wires and proceed to the discussion.

Discussion

In this experiment, you observed the operation of a common-emitter amplifier and noted its effects on the input signal. You noticed that the amplitude of the output signal was larger than that of the input signal. You also noticed that the output signal was 180 degrees out of phase with the input signal. This phase inversion of the input signal is the most distinctive characteristic of the common-emitter configuration. The common-emitter configuration is the only one of the three basic configurations that can invert the phase of the input signal. The common emitter configuration also has high to medium current, voltage, and power gains.

Summary

In this experiment, you applied a sine wave signal to a common-emitter transistor amplifier. The transistor is connected so that the very low base current controls the much larger collector current. The voltage gain is approximately equal to the collector resistor divided by the emitter resistor. In this case, $A_V = 1000/100 = 10$.

The common-emitter is the only arrangement to provide a phase inversion in the amplified signal. The output signal is 180 degrees out-of-phase with the input signal. This means that a positive alternation at the input causes a negative alternation at the output.

Experiment 10
Common-Collector Amplifier Characteristics

Purpose

1. To apply a sine wave signal to a common-collector transistor amplifier and measure some of its important characteristics.
2. To compare the input signal to the output signal in terms of amplitude and phase relationship.

Introduction

Experiment 10 is located in Block 10 on the lower right side of Circuit Board #1 as shown in Figure E10-1. All jumper locations mentioned in this experiment will refer to this block or to the Circuit Board's Interface Panel.

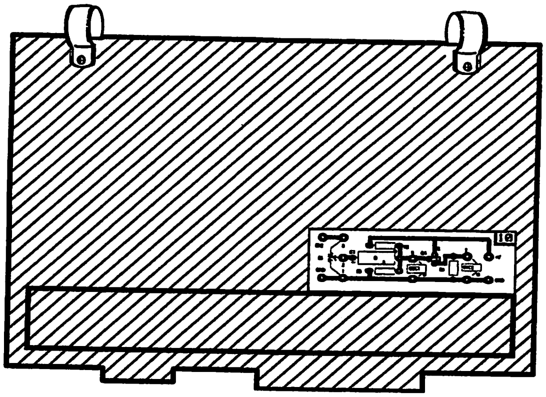


Figure E10-1
Block 10 of Circuit Board #1.

The common-collector circuit has a large number of applications in electronic circuits. Therefore, it is important that you become familiar with its characteristics. Common-collector amplifier circuits are also frequently called emitter followers.

In this experiment, you will construct an emitter-follower circuit on your Trainer and apply a signal to the circuit. You will then observe the input and output signals and note their phase relationship and relative amplitudes. You will also calculate the gain of the circuit.

Material Required

- 1 ETW-3600 Analog Trainer
- 1 ETW-3567 Accessory Backpack
- 1 ETB-6103
    - 1 Board #1
    - 1 Red jumper wire
    - 1 Black jumper wire
    - 3 Orange jumper wires
    - 1 Blue jumper wire
- 1 Dual-trace oscilloscope

Procedure

1. With the Trainer turned off, install Circuit Board #1. Make sure that Board #1 is OFF. Also make sure all Trainer controls are turned fully counterclockwise.

2. Refer to Figure E10-2. Install the red and black jumper wires to connect the Panel +DC and GND terminals to the block's +V and GND terminals. Then use the three orange jumper wires to connect the Panel's 100 kΩ terminals to the terminals of R1 in the block. Finally, use the blue jumper wire to connect the Panel's SINE terminal to the SINE terminal in the block.

   In this circuit, R2 and R3 develop the bias for the transistor, while R4 serves as the emitter load. C1 couples the signal from the sinewave generator to the base of the transistor.

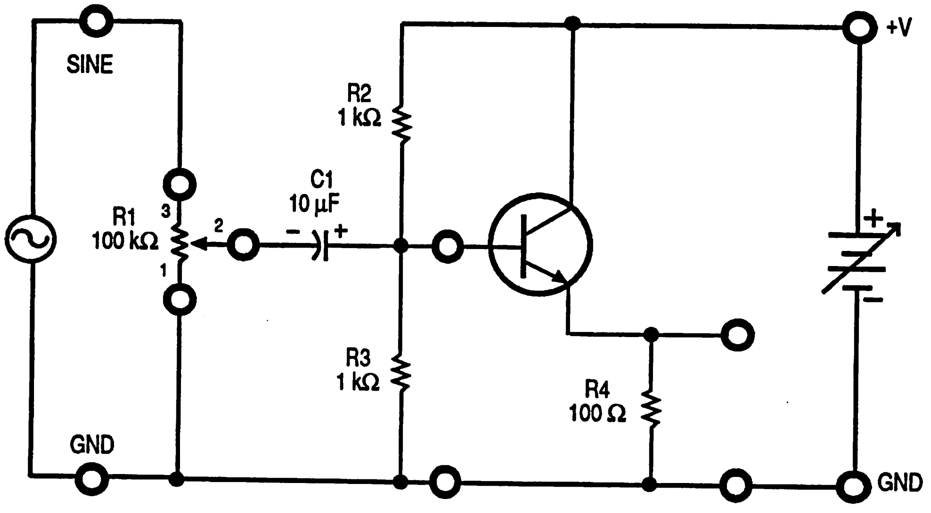


Figure 10-2
Circuit for Experiment 10.

3. Set the Trainer's generator frequency control to 200 Hz and set the range switch to the ×1 position.

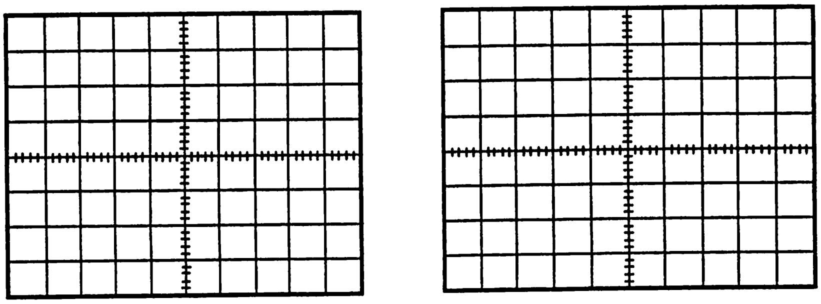
4. On the oscilloscope, set the TIME/CM to 1 ms/div. Also set the Y1 VOLTS/CM switch to the 1 V/div position and the Y2 VOLTS/CM switch to the 1 V/div position.

5. Connect the test lead from Y1 of your oscilloscope to the transistor base lead (OSC1) and the ground clip lead to GND.

6. Switch the Trainer ON and then Board #1 ON. Adjust the Trainer's + DC voltage control fully clockwise.

7. Observe the input signal. Then adjust the 100 kilohm potentiometer for a 1 $V_{P\text{-}P}$ signal. Record the waveform and its amplitude, in volts, in Figure E10-3A. Switch Board #1 OFF.

8. Connect the Y2 channel test lead to the emitter and the ground clip lead to GND. Switch Board #1 ON and view the output signal on channel Y2. Are the two signals in phase? ______ (yes/no). Record the signal amplitude and waveform in Figure E10-3B.



Ⓐ INPUT SIGNAL (E_{in}) = ________ V_{p-p}
1 V/CM 1 mS/CM

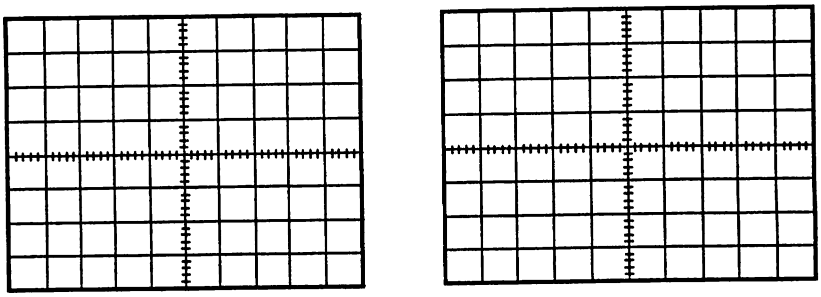
Ⓑ OUTPUT SIGNAL (E_{out}) = ________ V_{p-p}
1 V/CM 1 mS/CM

Figure E10-3
Record of the common emitter waveforms.

9. Using the value of E_{in} in Figure E10-3A and E_{out} in Figure E10-3B, calculate the voltage gain of the circuit.

A_V = ________

10. Return to Experiment 9 (and Block 9) and redo steps 1 through 7. Then in step 8, instead of connecting the Y2 scope lead to the collector of the transistor, connect it to the emitter. Record the signal amplitudes and waveforms of the input and output signals in Figure E10-4.



Ⓐ INPUT SIGNAL (E_{in}) = ________ V_{p-p}
0.5 V/CM 1 mS/CM

Ⓑ OUTPUT SIGNAL (E_{out}) = ________ V_{p-p}
0.5 V/CM 1 mS/CM

Figure E10-4
Record for step 10 waveforms.

11. Using the value of E_{in} in Figure E10-4A and E_{out} in Figure E10-4B, calculate the voltage gain of the circuit.

A_V = ______

12. This completes the experiment. Turn off the Trainer and Board #1. Remove all the jumper wires and proceed to the discussion.

Discussion

In this experiment, you observed the operation of a common-collector amplifier circuit. When you observed the waveforms and calculated the gain, you determined that circuit voltage gain was approximately 1 or unity. It should have been slightly less than unity. This is because the amplitude of the input signal is equal to or slightly greater than that of the output. Even though the common-collector circuit configuration has a voltage gain of less than unity, it is widely used in electronic devices as an impedance matching circuit, isolation amplifier, or as a buffer amplifier. The common-collector amplifier has a high current gain and a medium power gain with a high input impedance and a very low output impedance.

In step 10, you obtained a common-collector output from a common-emitter circuit. When a signal is measured or used as an output, at the emitter of a transistor, the circuit becomes a common-collector circuit. This is true even when there is a collector resistor in the circuit. You found in step 10 and 11 that the input and output signals were in phase and the gain was close to unity. Despite the different circuits, there is little effect on the emitter signal.

Summary

In the common-collector configuration, the input signal is applied to the base of the transistor. In order to forward bias the emitter junction, the DC voltage on the emitter must always be slightly less (about 0.6 volts for silicon) than the voltage on the base. As a result, the DC output voltage at the emitter will always be slightly less than the input voltage at the base. This results in a voltage gain of less than one, but very close to one. The voltage at the emitter tends to follow proportionally to the voltage on the base. This is why the common-collector is referred to as an emitter-follower

Experiment 11
NPN Transistor Amplifier

Purpose

1. To construct a basic NPN amplifier.
2. To analyze the amplifier's components and their functions.
3. To evaluate the amplifier under a variety of circuit parameters using test equipment.
4. To demonstrate and explain the terms saturation and cutoff.

Introduction

Experiment 11 is located in Block 11 of Circuit Board #2 as shown in Figure E11-1. All jumper locations mentioned in this experiment will refer to this block or to the Circuit Board's Interface Panel.

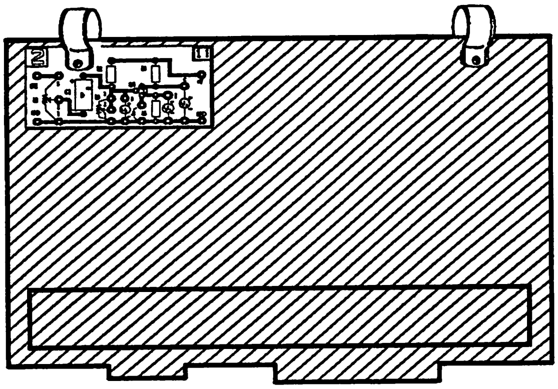


Figure E11-1
Block 11 of Circuit Board #2.

In this experiment, you will construct a circuit using an NPN bipolar transistor and other components. You will then examine the circuit using test equipment to verify its operation. You will also examine the various components in the circuit and determine their effect on the circuit. You will also examine the circuit under a variety of changing conditions.

Material Required

- 1 ETW-3600 Analog Trainer
- 1 ETW-3567 Accessory Backpack
- 1 ETB-6103
  - 1 Board #2
  - 1 Red jumper wire
  - 1 Black jumper wire
  - 3 Orange jumper wires
  - 3 Blue jumper wires
  - 1 White jumper wire
  - 1 Yellow jumper wire
- 1 Dual-trace oscilloscope

Procedure

1. With the Trainer turned off, install Circuit Board #2. Make sure that Board #2 is OFF. Also make sure all Trainer controls are turned fully counterclockwise.

2. Refer to Figure E11-2. Install the red and black jumper wires to connect the Panel's +DC and GND terminals to the block's +V and GND terminals. Then use the three orange jumper wires to connect the Panel's 100 kΩ terminals to the terminals of R1 in the block. Use the three blue jumper wires to connect the Panel's 1 kΩ terminals to the terminals of R3 in the block. With the yellow jumper wire, connect the Panel's SINE output terminal to the SINE terminal in the block. And finally, install a white jumper wire at J1.

3. Turn the Trainer ON and adjust the Trainer's +DC supply voltage for +10 volts at the power supply output terminals on the Trainer.

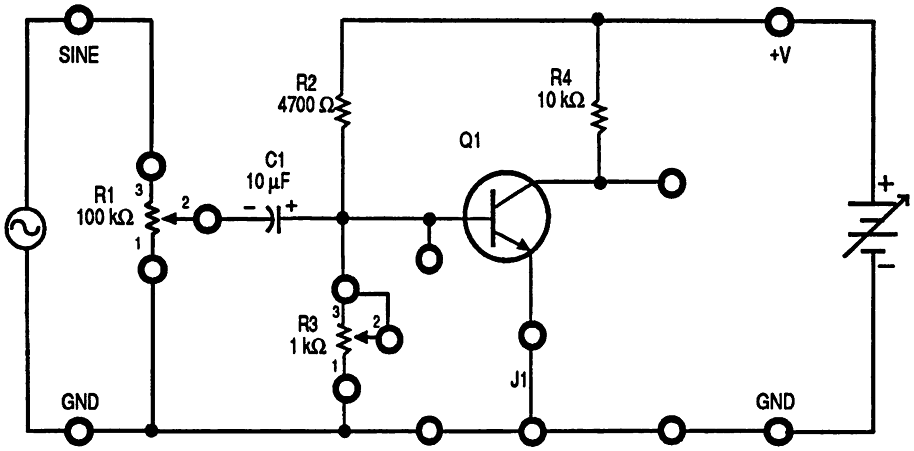


Figure E11-2
Circuit for Experiment 11.

4. Preset the following Trainer functions.

   Generator to 1 kHz (range switch to ×1).

   100 kilohm potentiometer (R1) to midrange.

   1 kilohm potentiometer (R3) to fully counterclockwise.

5. Set the Trainer's multimeter to measure +DC voltage and then connect it to the base of the transistor (V_B).

6. Turn Board #2 ON and slowly adjust R3 clockwise until the base voltage (V_B) equals 0.4 volts. Now measure the voltage at the collector (V_C) of the transistor. V_C equals ______ volts. Record this voltage in the table in Figure 11-3 opposite the V_B of 0.4 volts.

V_B	V_C
0.4	
0.5	
0.6	
0.7	
0.8	

Figure 11-3
Table for base and collector voltages.

7. Slowly adjust R3 in 0.1-volt steps and measure the resulting collector voltages. Record these measurements in the table of Figure 11-3 in the space opposite the base voltage setting. After measuring the voltages, switch Board #2 OFF.

Discussion

From the table in Figure 11-3, notice how V_C stayed at approximately 10 volts until the base-emitter barrier voltage was exceeded. Since the transistor is not conducting until then, the transistor is said to be in cutoff. When the barrier voltage is exceeded, the transistor begins to conduct current. As you saw, this is about 0.6 to 0.7 volts. When the transistor conducts, V_C is reduced due to the voltage drop across the load resistor R4.

If you were to keep increasing the base voltage past a certain point, you would find that V_C would not go any lower. In this case, the transistor would be conducting the maximum amount of current determined by the load resistor. This is called saturation.

Procedure (Cont.)

8. Switch Board #2 ON and carefully adjust R3 until V_C equals approximately 6 volts. Enter the exact collector voltage (V_C) in the first line of the table in Figure E11-4 in the appropriate column. Then measure and enter the exact base voltage opposite the collector voltage in the same line. Use the meter's 2V range and measure the base voltage to three decimal places.

	V_C	V_B
STEP 8		
STEP 9		
STEP 10 (ΔV)		

Figure E11-4
Table for steps 8 and 9.

9. Now slowly adjust R3 for a 0.02 volts higher base voltage than that measured in step 8. Enter this voltage in the second line of the table in Figure E11-4 in the appropriate column. Then measure the collector voltage and enter that value in the table.

10. Subtract the collector and base voltages measured in step 9 from those in step 8 to obtain the amount of change (Δ = change symbol) in each reading. Enter these values in the last line of the table in Figure E11-4.

11. Using the base and collector voltage values obtained in step 10, calculate the voltage gain of the circuit shown in Figure E11-2.

$$A_V = \frac{\Delta V_C}{\Delta V_B} = \frac{V_{C_1} - V_{C_2}}{V_{B_1} - V_{B_2}}$$

A_V = __________

12. Set the controls on your oscilloscope as follows:

    Channel Y1 volts/cm switch to 10 mV and for **AC coupling.**

    Channel Y2 volts/cm switch to 1 V and **DC coupling.**

    Trigger mode switch to AC.

    Time/cm switch to 0.2 ms.

    Turn the oscilloscope on and adjust the Y1 position control until the trace is displayed above the center line. Adjust the Y2 position control until the trace is displayed below the center line. Connect the Y1 oscilloscope probe to the transistor's base and the Y2 probe to the transistor's collector.

13. Turn R1 (100 kΩ control) fully counterclockwise. Adjust R3 for a reading of about 4 volts at the transistor's collector. Then slowly increase R1 until the output waveform on channel Y2 begins to clip or flatten on the top or bottom of the waveform. Now decrease R1 until you have an undistorted waveform displayed on the scope. Your display should resemble the display shown in Figure E11-5.

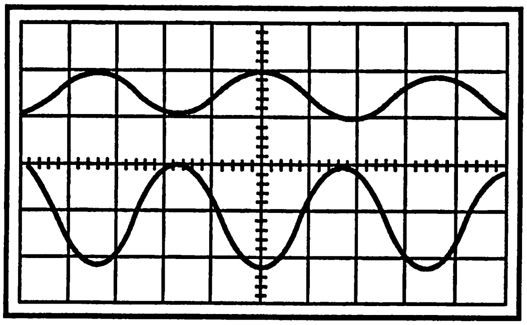


Figure E11-5
Oscilloscope display for step 13.

14. Compare the phase of the input sine wave on channel Y1 to the output waveform on channel Y2. Is the output in-phase or out-of-phase with the input? ____________ . Compare the amplitudes of the input and output waveforms. What is the input amplitude? $V_{B_{P\text{-}P}}$ = ______ . What is the output amplitude? $V_{C_{P\text{-}P}}$ = ______ .

15. Using the input and output amplitudes obtained in step 14, calculate the gain of the circuit.

$$\text{Gain} = \frac{V_{C_{P\text{-}P}}}{V_{B_{P\text{-}P}}}$$

Gain = ____________

16. Compare the gain calculated in step 15 (using input and output amplitudes) to the gain calculated in step 11 using base and collector voltages.

17. While observing the scope, slowly increase R1 until the output waveform becomes distorted. Why does the waveform become distorted? ____
____.

18. Now decrease R1 until the distortion in the output just disappears. For this step, we want the transistor to be on the verge of distortion. After R1 is adjusted, grasp the transistor between your finger and thumb. What happened to the output waveform? ______
____
__________________________. Why did it happen? ____________
____
____
____.

19. Turn Board #2 OFF.

Discussion

In this part of the experiment you saw that the output signal amplitude is higher than the input signal's amplitude. You also saw how the output waveform was out-of phase from the input signal. By comparing the input and output waveforms, you could see that they were 180 degrees out of phase. This is called polarity inversion.

Then using the amplitudes of the input and output waveforms, you again calculated the gain of the circuit. From your calculations, and comparing your result with that obtained in step 11, you found that they were approximately the same. You can use either method to calculate the approximate gain of a transistor amplifier.

In step 17 you demonstrated that when the input signal is too large the transistor is driven into saturation. This is indicated by the flattening or clipping of the negative peak and means that the supply voltage (10 volts) has been dropped across the transistor's load resistor. When a transistor is saturated it is conducting very hard and there is little voltage from collector to emitter.

In step 18 you applied heat to the transistor. In this case, it was your own body heat. You noticed that after a few seconds of heat the waveform started to increase in amplitude and the signal drifted down the scope's display. In fact, it should have increased until it saturated. This illustrates the fact that a transistor's gain (beta) increases with an increase in temperature. This makes the circuit unstable under varying temperature conditions.

Procedure (Cont.)

20. Remove J1 from the circuit. Now the circuit appears as shown in Figure E11-6 with R5 (1 kΩ) between the emitter and ground.

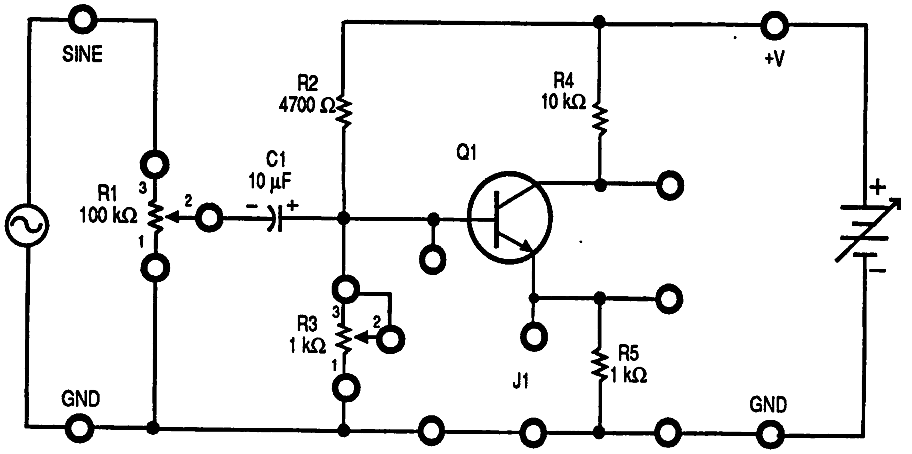


Figure E11-6
Circuit for step 20.

21. Connect your meter to the base of the transistor. With R1 and R3 fully counterclockwise, turn Board #2 ON. While monitoring the base voltage, slowly adjust R3 from 0.4 volts to 1.6 volts in 0.1-volt steps. Measure the resulting collector voltage at each step and record it in the table in Figure E11-7. Also measure the voltage at the emitter and then calculate the resulting collector current. (We are assuming that the collector current is the same as the emitter current because the α of this transistor is nearly equal to 1.)

V_B	V_C	V_E	$I_C = V_E/1\ k\Omega$ ($I_C \approx I_E$)
0.4			
0.5			
0.6			
0.7			
0.8			
0.9			
1.0			
1.1			
1.2			
1.3			
1.4			
1.5			
1.6			

Figure 11-7
Table for step 21.

22. Using the base voltages of 1.0 volt and 1.2 volts in the table above, calculate the change in emitter voltage versus base voltage, and collector voltage versus base voltage.

Common Collector	Common Emitter
$\frac{\Delta V_E}{\Delta V_B} = \frac{V_{E_2} - V_{E_1}}{V_{B_2} - V_{B_1}}$	$\frac{\Delta V_C}{\Delta V_B} = \frac{V_{C_2} - V_{C_1}}{V_{B_2} - V_{B_1}}$
$\frac{\Delta V_E}{\Delta V_B} =$ __________	$\frac{\Delta V_C}{\Delta V_B} =$ __________

23. Compare this circuit with the common-collector circuit in Experiment 10. Are they the same? ______ . Does the gain (A_V) of the common-collector circuit match the gain calculated in step 22? __________.

24. Set the base voltage for 0.9 volts. Set R1 to its midrange position. With the scope, compare the collector output (Y2) to the input (Y1). Is the output in- or out-of-phase with the input? __________ . Calculate the gain as in step 15. $A_V =$ ______ . Compare this gain with that calculated in step 22. Move the Y2 probe to the emitter of the transistor. Is the emitter waveform in- or out-of-phase with the input? __________ .

25. Reconnect the Y2 scope probe to the collector. Adjust R1 for a 4 volt peak-to-peak signal at the collector. Keep increasing R1 until the output just begins to distort. Once again apply heat with your fingers and note the response of the transistor output. Did the output change? ____________________ .

26. Decrease R1 and watch for the distortion to disappear from the bottom of the signal. As this point, the signal will drift up the scope's display. (If this does not happen, check ch. Y2 and make sure it is in DC coupling.) This is the DC component of the signal becoming more positive. Keep decreasing R1 until the tops of the waveform begin to flatten. What is the voltage of the "flat" portion of the waveform? ______ . Explain why this happens. ______ ____ .

27. Increase R1 and adjust R3 for the largest waveform at the collector without any distortion. What is the peak-to-peak voltage at the collector? $V_{CP\text{-}P}$ ______ . What is limiting this voltage? __________ ____ .

    Now rotate the Trainer's + supply control fully clockwise for maximum +V voltage and then repeat this step.

28. Compare the output with the emitter resistor (R5) in and out of the circuit. Is there any difference in outputs? ____________ ____ .

29. Turn the Trainer and Board #2 OFF.

Discussion

When the 1 kilohm resistor is connected to the emitter of the transistor it adds resistance to the emitter circuit. And when a resistor is added in series, current flow decreases. Therefore, collector current decreases.

From the voltages measured in step 21, you saw that the voltage across the emitter resistor followed the base voltage. This is another way of saying that the emitter resistor provides feedback bias to the amplifier. This emitter feedback bias is degenerative feedback and it always decreases gain. The emitter resistor develops a voltage and the base must now see a difference of a base-emitter junction voltage plus any voltage developed across the emitter resistor before conduction starts.

Since the voltage across the emitter resistor follows the base voltage, a change in emitter current will follow a change in base voltage. For example, a 0.1 volt change in V_B creates about a 0.1 volt change in V_E. This produces a change in current through the emitter resistor R5.

Since the transistor you are using has a β over 100 then its α is greater than 0.99. This means that over 99% of the emitter current goes through the load resistor (R_L), in this case R4. Therefore, any change in the voltage across the emitter resistor results in a voltage change of R_L/R_E at V_C. This makes the gain, A_V, approximately R_L/R_E.

The addition of the emitter resistor also provides another output connection. You should have noticed that this makes it identical to the common-collector circuit. When the output is taken across the emitter resistor, the output voltage is approximately (slightly less) the same amplitude as the input voltage. The input and output signals are also in phase.

In step 25 you should have noticed that the transistor's response to heat was much slower than without the emitter resistor. Thus, a major reason for using a resistor in the emitter lead is improved thermal (temperature) stability. However, to get the improved thermal stability you had to sacrifice some of the amplifier's gain capabilities.

In step 26 you discovered that the output waveform begins to flatten when the collector voltage reaches the power supply voltage (+V). At this time the transistor is in cutoff with little or no current flow. Therefore $V_C = +V$. The maximum output waveform is slightly less than +V. And, by increasing +V, a larger output amplitude is achieved.

Summary

In this experiment you analyzed an NPN transistor amplifier and evaluated it under a variety of circuit parameters. You learned about cutoff and saturation and saw how a transistor operates under both conditions. By analyzing the circuit with and without an emitter resistor, you found that it adds stability to the circuit at the expense of gain. You also found the output waveform at the emitter follows the input in phase at approximately the same amplitude. The output at the collector is amplified and out-of-phase with the input.

Experiment 12
Junction FET Characteristics

Purpose

1. To demonstrate the operation of a typical junction FET.
2. To calculate the FET's transconductance.

Introduction

Experiment 12 is located in Block 12 in the left middle of Circuit Board #2 as shown in Figure E12-1. All jumper locations mentioned in this experiment will refer to this block or to the Circuit Board's Interface Panel.

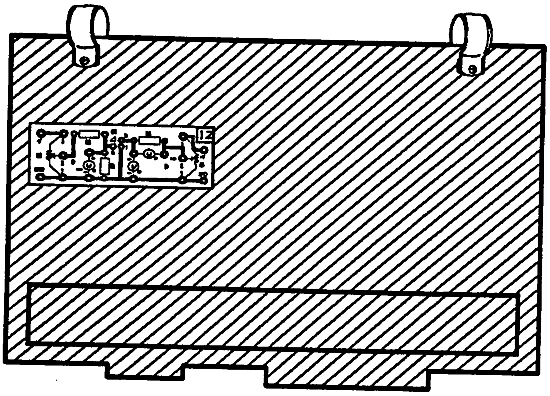


Figure E12-1
Block 12 of Circuit Board #2.

In this experiment, you will examine the relationship between the gate-to-source voltage (V_{GS}), the drain current (I_D), and the drain-to-source voltage (V_{DS}) in an N-channel junction FET. You will first measure and record the corresponding V_{GS}, I_D, and V_{DS} values and then plot these values to form a set of drain characteristic curves. Finally, you will complete the experiment by using these curves to determine the transconductance of the FET.

Material Required

- 1 ETW-3600 Analog Trainer
- 1 ETW-3567 Accessory Backpack
- 1 ETB-6103
    - 1 Board #2
    - 1 Red jumper wire
    - 1 Black jumper wire
    - 1 Green jumper wire
    - 3 Orange jumper wires
    - 3 Blue jumper wires

Procedure

1. With the Trainer turned off, install Circuit Board #2. Make sure that Board #2 is OFF. Also make sure all Trainer controls are turned fully counterclockwise.

2. Refer to Figure E12-2. Install the red and black jumper wires to connect the Panel's +DC and GND terminals to the block's +V and GND terminals. Then install the green jumper wire between –DC on the Panel and –V in the block. Use the three orange and three blue jumper wires to connect the Panel's 100k and 1k terminals to R1 and R5 in Block 12.

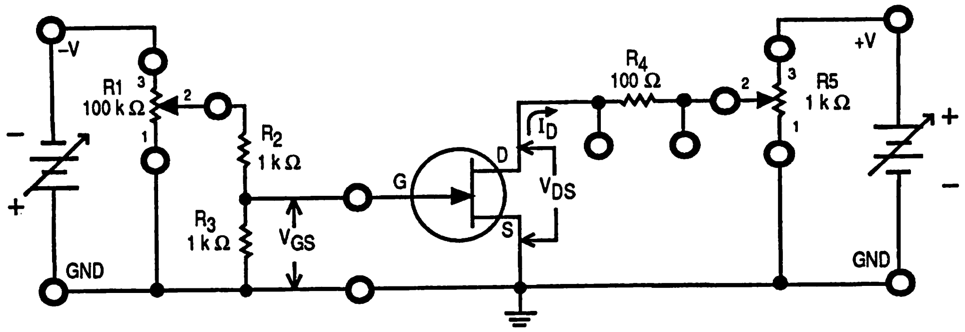


Figure E12-2
Circuit for Experiment 12.

3. Turn the Trainer ON. Then adjust the Trainer's +DC supply voltage fully clockwise. In the circuit, you will use R5 to control the drain-to-source voltage (V_{DS}). The drain current flowing through the FET must pass through a 100 ohm resistor (R4). As you proceed through this experiment, you will periodically measure the voltage across R4 (V_{ID}), then calculate I_D.

4. Adjust the Trainer's –DC supply voltage control to its 12 o'clock position. This voltage is applied to the 100 kilohm potentiometer (R1). You will use R1 to control the voltage applied to resistors R2 (1 kΩ) and R3 (1 kΩ). These resistors will divide the voltage taken from R1. The reduced voltage which appears across R3 serves as the gate-to-source bias voltage (V_{GS}).

5. Leave potentiometer R1 set full counterclockwise so that the gate-to-source voltage (V_{GS}) applied to the FET will be zero. Measure the V_{GS} with your meter. If the voltage is not zero, remove the green jumper wire from the Panel's – terminal for steps 5 through 7. Some trainers may have a residual voltage at the low end. Adjust potentiometer R5 until the drain-to-source voltage (V_{DS}) is equal to 1 volt (measure this voltage with your voltmeter).

6. Now measure the voltage across R4. Use this voltage reading and the resistance of R4 (100 ohms) to calculate the FET's drain current (I_D). Record your calculated I_D value (in milliamperes) immediately below the V_{DS} value of 1 volt in the table provided in Figure E12-3.

$V_{GS} = 0$								
V_{DS} (VOLTS)	1	2	3	4	5	6	7	8
I_D (MILLIAMPERES)								

Figure E12-3

Record of I_D values when V_{GS} equals zero.

7. Complete the table in Figure E12-3 by adjusting V_{DS} to the remaining values listed in the table and recording the corresponding values of I_D. To do this, simply repeat steps 5 and 6 for each value of V_{DS} indicated. When you complete the table in Figure E12-3, you will have a permanent record of I_D values over a range of V_{DS} values when V_{GS} is equal to zero. If you removed the green jumper wire from the Panel's –DC terminal in step 5, reinstall the jumper.

8. Now adjust potentiometer R1 so that V_{GS} is equal to –0.25 volts.

9. Without disturbing the setting of R1, adjust potentiometer R5 until V_{DS} is equal to 1 volt.

10. Now measure the voltage across R4. Use this voltage reading and the resistance of R4 (100 ohms) to calculate I_D. Record your calculated I_D value (in milliamperes) below the V_{DS} value of 1 volt in the table provided in Figure E12-4.

V_{GS} = −0.25 VOLTS								
V_{DS} (VOLTS)	1	2	3	4	5	6	7	8
I_D (MILLIAMPERES)								

Figure E12-4

Record of I_D values when V_{GS} equals −0.25 volts.

11. Complete the table in Figure E12-4 by adjusting V_{DS} to the remaining values indicated and recording the corresponding values of I_D. To do this, simply repeat steps 9 and 10 for each value of V_{DS} indicated. When you complete the table in Figure E12-4, you will have a record of I_D values over a range of V_{DS} values when V_{GS} is equal to −0.25 volts. A negative sign is placed before the V_{GS} value to indicate that the gate is negative with respect to the source.

12. Adjust potentiometer R1 so that V_{GS} is equal to −0.5 volts.

13. Without disturbing the setting of R1, adjust potentiometer R5 until V_{DS} is equal to 1 volt.

14. Measure the voltage across R4. Then use this voltage reading and the resistance of R4 (100 ohms) to calculate I_D. Record your calculated I_D value (in milliampere) below the V_{DS} value of 1 volt in the table provided in Figure E12-5.

V_{GS} = −0.5 VOLTS								
V_{DS} (VOLTS)	1	2	3	4	5	6	7	8
I_D (MILLIAMPERES)								

Figure E12-5

Record of I_D values when V_{GS} equals −0.5 volts.

15. Now complete the table in Figure E12-5 by repeating steps 13 and 14 for the remaining V_{DS} values indicated. When you complete this table, you will have a permanent record of I_D values over a range of V_{DS} values when V_{GS} is equal to −0.5 volts.

16. Adjust potentiometer R1 so that V_{GS} is equal to −0.75 volts.

17. Without disturbing the setting of R1, adjust potentiometer R5 until V_{DS} is equal to 1 volt.

18. Measure the voltage across R4. Then use this voltage reading and the resistance of R4 (100 ohms) to calculate I_D. Record your calculated I_D value (in milliamperes) below the V_{DS} value of 1 volt in the table provided in Figure E12-6.

V_{GS} = −0.75 VOLTS								
V_{DS} (VOLTS)	1	2	3	4	5	6	7	8
I_D (MILLIAMPERES)								

Figure E12-6
Record of I_D values when V_{GS} equals −0.75 volts.

19. Complete the table in Figure E12-6 by repeating steps 17 and 18 for the remaining V_{DS} values indicated. When you complete this table, you will have a record of I_D values over a range of V_{DS} values when V_{GS} is equal to −0.75 volts.

20. Now use the corresponding values of V_{DS} and I_D that you recorded in Figure E12-3, and plot the drain characteristic curves on the graph shown in Figure E12-7. Connect the various points plotted to form a continuous curve. Label this curve V_{GS} = 0.

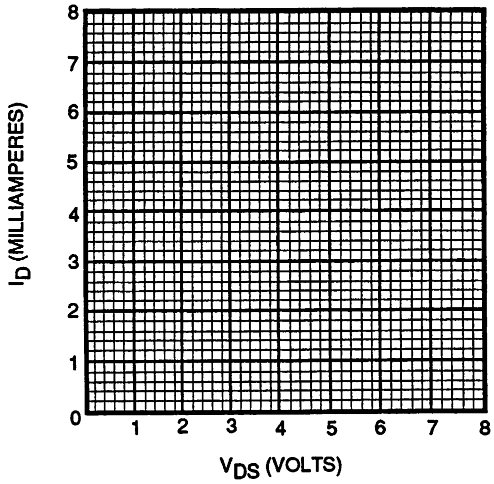


Figure E12-7
Record of V_{DS} and I_D values.

21. Use the corresponding values of V_{DS} and I_D in Figure E12-4 to plot a second curve on the graph of Figure E12-7. Label this curve $V_{GS} = -0.25$ volts.

22. Use the corresponding values of V_{DS} and I_D in Figure E12-5 to plot a third curve on the graph of Figure E12-7. Label this curve $V_{GS} = -0.5$ volts.

23. Use corresponding values of V_{DS} and I_D in Figure E12-6 to plot a fourth curve on the graph of Figure E12-7. Label this curve $V_{GS} = -0.75$ volts.

24. Now use the set of drain characteristic curves that you plotted in Figure E12-7 to determine the transconductance of the FET. Select a constant value of V_{DS} that is well above the pinch-off voltage (V_P) of the device (possibly 6 or 7 volts) and observe the change in I_D when V_{GS} changes from 0 to −0.25 volts. This will insure that your transconductance value will be measured in the pinch-off region of the device. Use the transconductance equation given below and record your results in the space provided below.

    Transconductance = $\Delta I_D / \Delta V_{GS}$

    Transconductance = ____________

25. Adjust V_{DS} between 6 to 8 volts. Increase V_{GS} until the drain current goes to zero. What is the value of V_{GS}? V_{GS} = ______ . This is called $V_{GS(off)}$.

26. Calculate the maximum I_D when $V_{GS} = 0$. This is called I_{DSS}. I_{DSS} = ____________ .

27. Your experiment is now complete. Turn off Board #2 and your Trainer.

Discussion

In this experiment, you observed the relationship between I_D, V_{DS}, and V_{GS} in an N-channel junction FET. You measured specific values of I_D over a range of V_{DS} values for several values of V_{GS} and then plotted these values to produce a set of drain characteristic curves. The curves that you plotted should resemble the ones shown in Figure 7-3 in the textbook. However, your curves were not plotted for low values of V_{DS} (between 0 and 1 volt) because of the difficulty in making accurate measurements within this region. Therefore, your curves do not begin at zero but instead begin at some value of I_D. Each curve should rise rapidly at first and then level off. At each higher value of V_{GS}, I_D should level off at a correspondingly lower value.

Next, you used your drain characteristic curves to determine the transconductance of the FET within its pinch-off region. You probably obtained a transconductance that was greater than 1500 micromhos (0.0015 mhos) but less than 5000 micromhos (0.005 mhos). The exact transconductance that you obtained is not extremely important since this value usually varies widely even among FET's of the same type. You should also have realized that a measure of transconductance was the reciprocal of a measure of resistance. Remember that resistance is measured in ohms and the unit of measure for transconductance is the mho (sometimes called siemens).

If you were not able to plot a drain characteristic curve for the highest value of V_{GS} given ($V_{GS} = -0.75$ volts) it was because your I_D values were all equal to zero. This simply means that a V_{GS} of -0.75 volts is high enough to cut off the drain current. In other words, the $V_{GS(off)}$ rating for your FET was exceeded. This could occur if your FET has an unusually high transconductance. In such a case the FET would require only a very small V_{GS} value to reduce its drain current to zero.

In steps 25 and 26 you determined two important FET specifications, I_{DSS} and $V_{GS(off)}$. I_{DSS} represents the drain current of the FET measured with the gate and source connected together. It is the maximum current that the FET will handle. $V_{GS(off)}$ represents the gate to source voltage required to shut off all of the drain current. This value is close to the pinch-off voltage (V_P) and the two values are often used interchangeably.

Summary

In this experiment, you examined the relationship between the gate-to-source voltage (V_{GS}), the drain current (I_D), and the drain-to-source voltage (V_{DS}) in an N-channel junction FET. You found out that V_{GS} controls the drain current which represents the output current that flows through the load. By measuring and recording corresponding V_{GS}, I_D, and V_{DS} values, you plotted a set of drain characteristic curves. Then you determined the transconductance of the FET from these curves. You also determined two important FET specifications, I_{DSS} and $V_{GS(off)}$.

Experiment 13
N-Channel Junction FET Amplifier

Purpose

1. To study the differences between the common-drain (source follower) and common-source FET amplifiers.
2. To determine the major differences between a bipolar transistor amplifier and an FET amplifier.
3. To show how to bias an FET amplifier.
4. To measure the input and output amplitude and phase relationships for two different amplifier configurations.

Introduction

Experiment 13 is located in Block 13 in the lower left of Circuit Board #2 as shown in Figure E13-1. All jumper locations mentioned in this experiment will refer to this block or to the Circuit Board's Interface Panel.

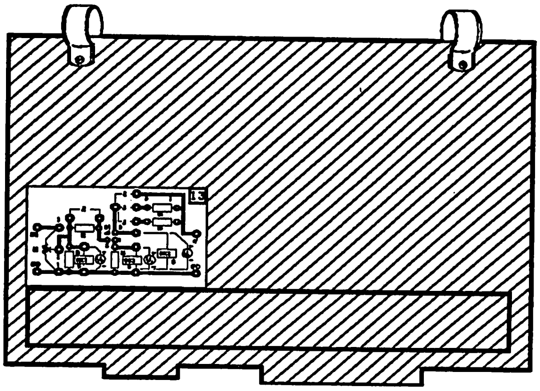


Figure E13-1
Block 13 of Circuit Board #2.

In this experiment, you will examine a common-drain circuit, a circuit that is similar to the common-collector bipolar transistor circuit. First, you will measure the voltages at the gate, source, and drain leads of the FET amplifier. Then you'll observe the amplitude and phase of the signals at the gate and source of the FET. Finally, you'll change the circuit's parameters and note their effects on the input and output waveforms.

Material Required

1 ETW-3600 Analog Trainer
1 ETW-3567 Accessory Backpack
1 ETB-6103
  1 Board #2
  1 Red jumper wire
  1 Black jumper wire
  1 Yellow jumper wire
  2 White jumper wires
  3 Orange jumper wires
1 Dual-trace oscilloscope

Procedure

1. With the Trainer turned off, install Circuit Board #2. Make sure that Board #2 is OFF. Also make sure all Trainer controls are turned fully counterclockwise. Set the Trainer's generator range switch to the 1× position.

2. Refer to Figure E12-2. Install the red and black jumper wires to connect the Panel's +DC and GND terminals to the block's +V and GND terminals. Then install the yellow jumper wire between the Panel's SINE terminal and the block's SINE terminal. Also install two white jumper wires, one at J1 and the other at J2. Use the three orange jumper wires to connect the Panel's 100k terminals to the terminals of R1 in Block 13.

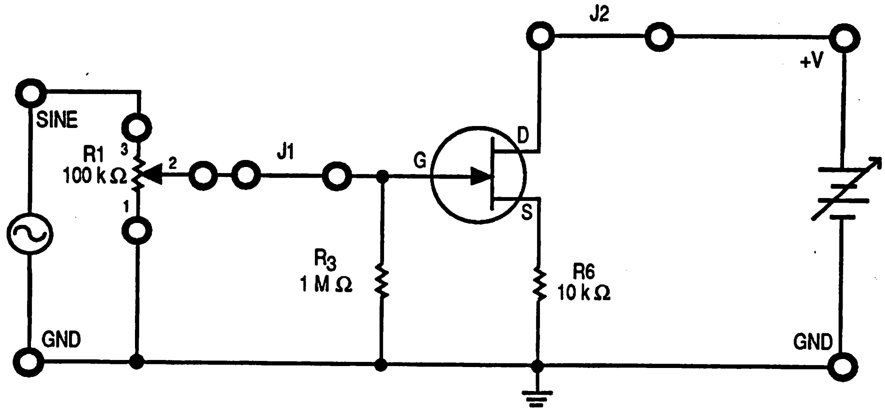


Figure E13-2
Circuit for step 2.

3. Turn the Trainer and Board #2 ON. Then adjust the Trainer's +DC supply voltage fully clockwise. Measure the voltage at the gate (V_G), drain (V_D), and source (V_S) of the FET. Record your measurements below.

V_G = ______ volts

V_D = ______ volts

V_S = ______ volts

Discussion

Since there is an extremely small (almost insignificant) current flow from the gate to the source, there is practically no current flow through R1 to ground. With little or no current flow through R1, there is no voltage developed across R1. Therefore, V_G is zero volts.

By connecting the drain directly to the power supply V_D equals the power supply voltage (approximately 14 volts).

V_S is determined by the FET parameters $V_{GS\,(off)}$ and I_{DSS} (maximum drain current), and by the resistor in the source path, R6. The voltage should be between 1 and 5 volts. The higher the $V_{GS\,(off)}$ and I_D, the higher will be V_S. Notice that the gate voltage (V_G) is 0 and the source voltage (V_S) is positive. This is another way of saying that the gate voltage is negative with respect to the source. You have already learned that this is necessary for the FET to operate properly. This voltage difference between the source and gate is developed by the source current flowing through the source resistor R_S (in this circuit it is R6). Again, this current is determined by the FET's parameters and R_S. Therefore, for a given FET and R_S, the circuit will adjust the current so that it precisely produces enough gate-to-source voltage for the correct voltage drop across R_S to balance the circuit. This is called "self bias" or "source bias."

Procedure (Cont.)

4. Set the controls on your oscilloscope as follows:

   Channel Y1 volts/cm switch to 0.5 V and AC coupling.

   Channel Y2 volts/cm switch to 0.5 V and DC coupling.

   Trigger mode switch to AC.

   Time/cm switch to 1.0 ms.

   Turn the oscilloscope on and adjust the Y1 position control until the trace is centered on a horizontal line above the center line. Adjust the Y2 position control until the trace is centered on a horizontal line below the center line. Connect the Y1 oscilloscope probe to the FET's gate and the Y2 probe to the FET's source.

5. Adjust R1 (the 100 kΩ control) for a 2 cm (2 squares) sine wave display on the scope. What is the peak-to-peak input amplitude at the gate? ______ . What is the peak-to-peak output amplitude at the source? ______ . Is the output in- or out-of-phase with the input? ____________ .

6. Remove the jumper wire at J1. By removing J1, what did you do to the circuit? ______________________________________ ______________________________________ . Was either the input or output waveform affected? ______ (yes/no).

7. Note the direction that the waveform shifted. Did the waveform shift above or below its zero reference line? ______ . Now slowly rotate R1 clockwise to increase the input signal until the waveform at the source becomes distorted. Does the waveform become distorted on the positive or negative peak? ____________. What is causing this distortion? ______________________________
____
____.

8. Switch Board #2 OFF.

Discussion

In step 5 you saw that the common-drain circuit cannot provide voltage amplification. You measured the sine wave voltage at the source and found that it was slightly less than the gate voltage. And, you saw that the voltage appearing at the source of the FET follows the voltage at the gate. With the scope you saw that both waveforms were in-phase. For this reason the circuit is often referred to as a source-follower. However, the output source voltage is always slightly less than the input causing a voltage gain that is slightly less than one.

By removing J1 in step 6, 10 megohms was added in series with the gate of the FET. You also saw that neither the input nor the output waveform was affected. This is because the input resistance of the common-drain circuit is extremely high. In fact, this circuit has a higher input resistance than any junction transistor configuration. A junction transistor emitter-follower (common-collector) circuit would not work with a 10 megohm resistor in series with the base because it has a much higher base current than an FET's gate current.

In step 7, you should have found that the waveform at the source is centered on a positive voltage. This was evident when the waveform moved upward after you switched the Y2 channel to DC coupling. When the output was distorted, the distortion occurred on the negative peak. This was caused by the negative peak trying to go below ground potential.

Procedure (Cont.)

9. Refer to Figure E13-3 and reinstall J1. Remove the jumper wire from J2 and install it at J3. Switch Board #2 ON.

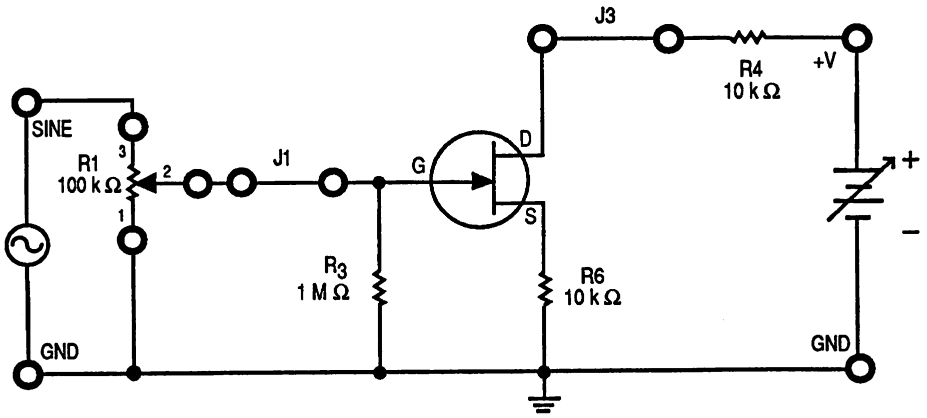


Figure E13-3
Circuit for step 9.

10. By installing a jumper wire at J3, R4 is added in series with the drain of the FET. Switch Board #2 ON and adjust the R1 for a input 2 cm high (1 volt peak-to-peak). Does the signal at the source change? ______ (yes/no). Why or why not? ________________
____.

11. Move the channel Y2 probe to the drain of the FET. What is the amplitude of the waveform? ____________. Is the waveform at the drain in- or out-of-phase with the input? ____________ .

12. Move the channel Y1 probe from the gate to the source of the FET. How does the amplitude of the source waveform compare to the drain waveform? ________________________________
________. How does the phase of the source waveform compare to the drain waveform? ________________________________.

13. Switch Board #2 OFF.

Discussion

When you added R4 in series with the drain of the FET you should have seen no change in the waveforms at the gate or the source. As you have learned, the waveform at the source depends predominately on the characteristics of the FET and R_S. The drain load has practically no effect.

In step 11, the waveform at the drain should be approximately the same amplitude. However, the waveform at the drain should be 180 degrees out of phase with the input waveform at the gate.

When you compared the difference between the source and drain waveforms in step 12, you should have noticed two things. One was the closeness in amplitudes and the other was that they were opposite in phase. The difference in amplitude is determined only by the mismatch of the source and drain resistors R6 and R4.

Refer to Figure E13-4 for the following example. Let's assume that the gate current is negligible. This means that, essentially, all of the current that flows through the drain resistor (R_D) also flows through the source resistor (R_S). If the resistors are equal, then the voltages developed across each must also be equal. Remember that the transconductance of the FET is the ratio of drain current I_D to the gate-to-source voltage (V_{GS}). Therefore the voltage drop across each resistor is in proportion to the input voltage and the transconductance (gm). From Figure E13-4, you can see that the drain resistor is connected at one end to +V (which is a constant voltage), and the source resistor is connected at one end to ground (also a constant voltage). If the current changes through them, the voltages at the source and drain must move in opposite directions. This causes the 180 degree phase shift.

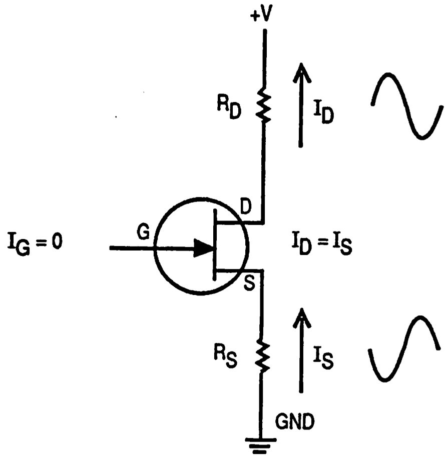


Figure E13-4
Phase shift in FET.

Procedure (Cont.)

14. From what you have learned in this experiment, what would you expect to happen if the drain resistor were changed from 10 kΩ to 20 kΩ? ______________________________
____.

15. Now remove the jumper wire at J3 and move it to J4. Switch Board #2 ON. With the Y2 probe still connected to the drain, does the waveform look as you predicted ______ (yes/no).

16. Move the Y1 probe back to the gate of the FET, what is the relationship between the input and the output of the amplifier? ______________________. Why? ______________
____.

17. Remove J1. Was there any change in either input or output waveforms? ______ (yes/no). Why? ______________________
____.

18. Increase the input amplitude with R1 until the output becomes distorted. How is the waveform distorted? ______________
_______. Why? ______________________________
____.

19. This completes the experiment. Turn off Board #2 and the Trainer. Remove all jumper wires.

Discussion

When you increased the drain resistor from 10 kΩ to 20 kΩ by moving the jumper wire from J3 to J4, the waveform at the drain should have increased by the same ratio (2 times). The source phase should be 180 degrees out from the input. Again, this is due to the same current flowing through the source and drain resistors. If you noted that the drain waveform is a little less than expected, it could be caused by the loading effect of the scope probe on the output.

Moving the Y1 channel probe back to the input shows that the overall voltage gain of the amplifier is close to a factor of 2. Removing J1 should have little or no effect because the input resistance of the FET is extremely high.

When you increased the signal, the output reached a point where the drain current went to 0 milliamps and the output voltage could not go above +V. This caused the output waveform to clip on the positive peak of the waveform that was trying to go past +V. It is also possible that FETs with a low I_{DSS} could distort the waveform at the negative peak. This occurs when the drain current tries (but cannot) to exceed I_{DSS}.

Summary

In this experiment, you examined the common-drain, also called a source-follower) amplifier. You were acquainted with biasing including self-bias. You saw that the common-drain circuit cannot provide voltage amplification. And, you saw that the voltage appearing at the source of the FET follows the voltage at the gate. You also saw that the input resistance of the common-drain circuit is extremely high.

When a drain resistor was added (moving the jumper wire from J2 to J3) and the output was taken from the drain, the circuit configuration changed to a common-source amplifier. While examining this circuit you measured input and output waveforms and noted their phase relationships. The waveform at the drain should be 180 degrees out-of-phase with the gate while the waveform at the source is in-phase with the gate. The amplitude of the waveform at the source should be slightly lower but never higher than the amplitude of the gate. The difference in amplitude between the source and drain is determined by the source and drain resistors.

You can see the similarities between the: common-source and common-emitter amplifiers, the common-drain and common-collector configurations, and the common-gate and common-base amplifier. FETs are generally used in applications where a high input impedance is needed. Junction transistors are used for higher gain and higher frequencies.

Experiment 14
SCR Characteristics

Purpose

1. To examine the operation of a typical SCR.
2. To demonstrate a practical application of the SCR.

Introduction

Experiment 14 is located in Blocks 14 I and 14 II in the middle of Circuit Board #2 as shown in Figure E14-1. All jumper locations mentioned in this experiment will refer to this block, to the Circuit Board's Interface Panel, or to the Trainer.

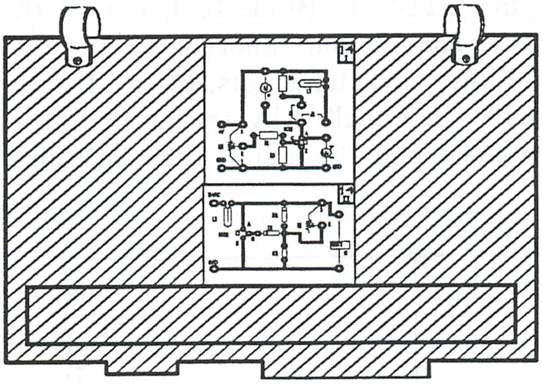


Figure E14-1
Blocks 14 I and 14 II of Circuit Board #2.

In this experiment, you will demonstrate the conditions required to turn on and turn off an SCR. You will do this by subjecting the SCR to its normal operating voltages and observing its operation using voltage measurements. Then, you will use a lamp to provide a visual indication of SCR operation. You will conclude the experiment by demonstrating the use of the SCR in a half-wave phase control circuit.

Material Required

- 1 ETW-3600 Analog Trainer
- 1 ETW-3567 Accessory Backpack
- 1 ETB-6103
  - 1 Board #2
  - 1 Red jumper wire
  - 1 Black jumper wire
  - 3 Blue jumper wires
  - 1 White jumper wire
  - 2 Violet jumper wires
  - 2 Orange jumper wires
- 1 Dual-trace oscilloscope

Procedure

1. With the Trainer turned off, install Circuit Board #2. Make sure that Board #2 is OFF. Also make sure all Trainer controls are turned fully counterclockwise.

2. Refer to Figure E14-2. In Block 14 I, install the red and black jumper wires to connect the Panel's +DC and GND terminals to the block's +V and GND terminals. Install the three blue jumper wires to connect the Panel's 1 kΩ terminals to the 1 kΩ terminals of R1 in the block. Finally, install the white jumper wire at J1.

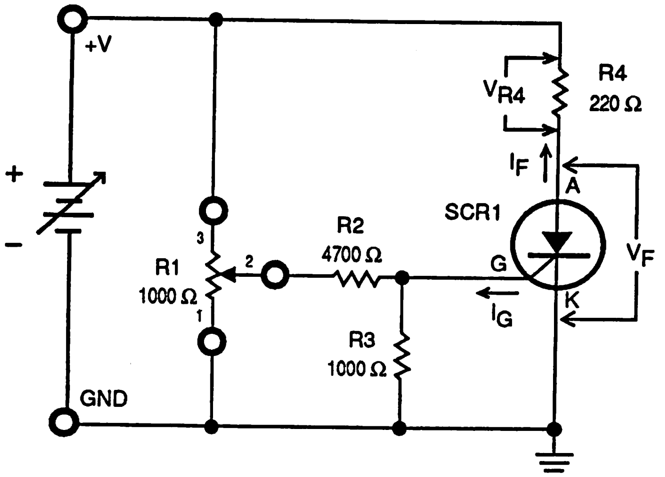


Figure E14-2
DC control SCR circuit.

3. Turn the Trainer on and adjust the positive DC power supply control for 10 volts at the power supply terminals. In this circuit, R1 is used to control the gate-to-cathode voltage, and the gate current (I_G).

4. Switch Board #2 ON and measure the SCR's anode-to-cathode voltage (designated as V_F). Record your voltage measurement in the appropriate space in the OFF column in the table provided in Figure E14-3. Your recorded value represents the forward voltage across the SCR when it is turned off.

5. Now measure the voltage drop across R4. Record this voltage (V_{R4}) in the appropriate space in the OFF column of the table provided in Figure E14-3. Your recorded value represents the voltage across R4 when the SCR is off.

6. Use the voltage dropped across R4 and the resistance of R4 to calculate the current through R4. Your calculated value of current represents the forward current (I_F) flowing through the SCR when it is turned off. Record this I_F value in the space provided in the OFF column of the table shown in Figure E14-3.

7. Connect your voltmeter across the SCR again and observe its forward voltage (V_F) as you adjust potentiometer R1 slowly clockwise. This will cause the gate current (I_G) to increase. Continue to turn R1 until you note a change in V_F. Then, stop turning R1 and record the new V_F value in the space provided in the ON column of Figure E14-3. Your recorded value represents the forward voltage across the SCR when it is turned on.

8. Measure the voltage dropped across R4 and record your measured voltage in the space provided in the ON column in the table of Figure E14-3. Your recorded value represents the voltage across R4 when the SCR is turned on.

9. Use the voltage drop across R4 obtained in step 8 and the resistance of R4 to calculate the current through R4. Your calculated value represents the forward current (I_F) flowing through the SCR when it is turned on. Record the value of (I_F), in milliamperes, in the space provided in the ON column of the table shown in Figure E14-3.

10. Adjust R1 to reduce I_G to zero. Now measure V_F and the voltage drop across R4 and use these voltage readings to determine if the SCR is still on, or if the device has been turned off. According to your readings the SCR is turned ______ (on/off).

SCR CONDITION	OFF	ON
V_F (VOLTS)		
V_{R4} (VOLTS)		
I_F (MILLIAMPERES)		

Figure 14-3
Record of DC data from steps 4 thru 10.

11. Without switching Board #2 OFF, disconnect one end of jumper J1, and then, immediately reinstall this jumper lead. This will momentarily reduce I_F to zero. Measure V_F and the voltage drop across R4 again, and determine if the SCR is on or off. According to your measurements the SCR is turned ______ (on/off).

12. Switch Board #2 OFF and move the white jumper wire from J1 to J2. By moving the jumper wire you remove R4 and place a lamp in its place in the circuit as shown in Figure E14-4. This lamp will provide a visual indication of the SCR's operating state. It will light (turn on) when the SCR switches to its "on" state and it will turn off when the SCR switches to its "off" state. Make sure that I_G equals zero by adjusting potentiometer R1 fully counterclockwise. Now turn on Board #2 and observe the lamp. The lamp is ______ (on/off).

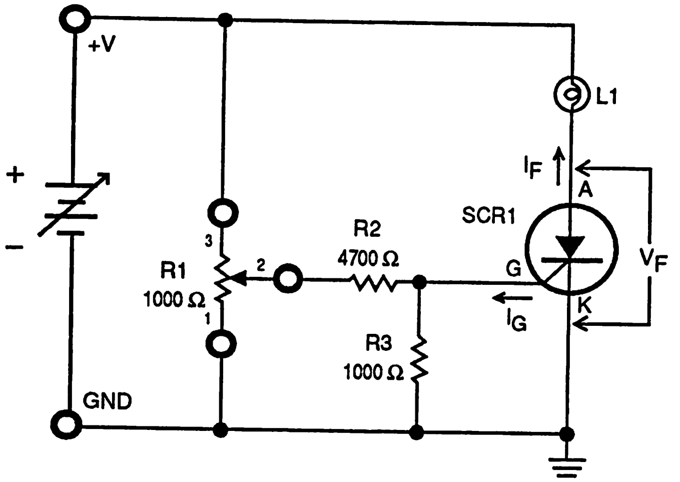


Figure 14-4
Circuit for steps 12 thru 15.

13. Adjust the potentiometer R1 until the lamp changes state. The lamp is ______ (on/off).

14. Adjust the potentiometer R1 fully counterclockwise to reduce I_G to zero. The lamp is ______ (on/off).

15. Turn off Circuit Board #2. Wait at least 10 seconds and then turn it on again. The lamp is ______ (on/off).

16. Turn Board #2 and the Trainer OFF. Remove all the jumper wires..

Discussion

In this portion of the experiment, you demonstrated the conditions necessary to turn on and turn off an SCR. First, you applied voltage to the SCR and its series resistor (R4) but you did not allow gate current to flow through the device. Under these conditions the SCR was in the off state. Next, you measured the SCR's forward voltage (V_F) and the voltage dropped across the series resistor R4. You found that V_F was almost equal to the applied voltage (approximately 10 volts) and that the voltage drop across R4 was approximately zero. You also calculated the SCR's forward current (I_F) and determined that it was near zero at this time.

Then, you increased the gate current (I_G) until the SCR turned on, and again measured the voltage dropped across R4. You should have obtained a V_F value of 1 volt or less and a corresponding voltage drop across R4 of 9 volts or more. The lower V_F value occurred because the SCR was conducting and its anode-to-cathode resistance was low. This allowed most of the supply voltage (10 volts) to appear across R4. The supply voltage used in this experiment was relatively low, therefore, the voltage dropped across the SCR was noticeable. However, in many applications the supply voltage is very high (100 volts or more) and the voltage dropped across the SCR is insignificant when compared to the voltage developed across the load. While the SCR was turned on you also calculated its forward current (I_F). You probably obtained an I_F value of 40 milliamperes or more.

At this time, you reduced I_G to zero and observed the condition of the SCR circuit by measuring V_F and the voltage dropped across R4. V_F should have remained low and unchanged while the voltage drop across R4 remained high and unchanged. This indicates that the SCR remained in the on state.

Next, you momentarily disconnected one end of jumper J1 and observed the condition of the circuit by again measuring V_F and the voltage dropped across R4. Your measurements should have indicated that the SCR was in the off state. The SCR switched to the off state because its forward current was reduced to zero, and was, therefore, forced to drop below the SCR's minimum holding current value. This holding current value was not actually determined since it is usually very low. The holding current for your SCR could be as low as several milliamperes.

Next, you replaced R4 with a lamp. The lamp served as a series load to provide a visual indication of the SCR's operating condition. First, you applied voltage to the SCR circuit while holding I_G to zero. The lamp should have remained off to indicate that the SCR was in the "off" state. Then, you increased I_G, and the lamp turned on to indicate that the SCR had changed state. Next, you adjusted R1 to reduce I_G to zero, however, the lamp should have remained on. This proved that once in the "on" state, reducing the gate voltage to zero would not turn off the SCR. Finally, you turned off the circuit board, waited a few seconds, and then turned the board back on, while holding I_G to zero. This should have caused the lamp to turn off, proving that in order to turn off the SCR, I_F must be momentarily reduced to zero by disconnecting the circuit or completely shutting it down. In either case, I_F drops below the holding value and allows the device to unlatch (internally) and change state.

Procedure (Cont.)

17. Refer to Figure E14-5. In Block 14 II, install the two violet jumper wires to connect the Trainer's LINE FREQ section to the block's 15VAC and GND terminals. Install two orange jumper wires to connect the Panel's 100 kΩ terminals 2 and 3 to the 100 kΩ terminals (2 and 3) of R1 in the block.

Potentiometer R1 is used as a variable resistance in series with the 0.1 microfarad capacitor (C1) to control the voltage at the gate of the SCR. The SCR in turn, controls the AC voltage applied to the lamp. Instead of controlling 120 volts AC like the more common household lamp control devices, you will be using the 15 volt AC power supply provided on your Trainer.

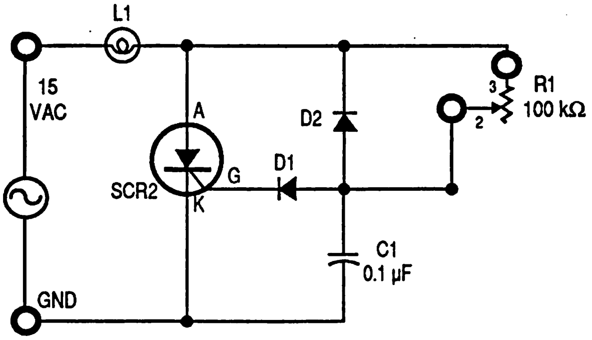


Figure E14-5
AC phase control SCR circuit.

18. Set the controls on your oscilloscope for 10 volts/cm and 5 milliseconds/cm. Connect the oscilloscope to the anode lead on the SCR. Adjust R1 so that its resistance is minimum (fully clockwise). Then turn your Trainer ON.

19. Observe the lamp as you increase the resistance of R1 (turning it counterclockwise). Adjust R1 until it is at maximum resistance (fully counterclockwise). Then return R1 to minimum resistance. Note the condition of the lamp as you adjust R1. Also, observe the signal on the oscilloscope as you adjust R1.

20. Turn off your Trainer and remove all jumper wires.

Discussion

In this part of the experiment, you demonstrated the use of an SCR in a half-wave phase control circuit. First, you adjusted R1 for minimum resistance. This should have caused the lamp to glow at maximum intensity. Then you increased the resistance of R1. This should have caused the intensity of the lamp to decrease. When R1 was at maximum resistance, the lamp should have been completely off. Returning R1 to minimum should have again increased the intensity of the lamp to maximum.

This experiment should have proved that the SCR can be used to vary the amount of power applied to a load. Although AC power was applied to the input of the circuit, the SCR allowed only a pulsating DC current to flow through the load. You should have seen waveforms similar to those shown in Figure 8-9 of the textbook as R1 was varied. Furthermore, by adjusting R1 the SCR's conduction time was varied, thus, controlling the average level of power applied to the load.

Summary

In the first part of this experiment, you examined the operation of a typical SCR. You found that merely forward biasing the SCR is not enough to switch the SCR to its "on" state. However, after applying a suitable gate current, the SCR switches "on" and current flows from cathode to anode. After turning "on," reducing the gate current to zero would not turn the SCR "off." In order to switch the SCR "off," you found it was necessary to reduce the anode-to-cathode voltage to almost zero before current flow would stop. Using a lamp in the circuit provided a visual indication of what you previously found.

In the second part of this experiment, you demonstrated a practical application of the SCR. You used an SCR to vary the amount of power to a lamp and thereby its brightness. You actually adjusted the SCR's conduction time, thus, you controlled the average level of voltage applied to the lamp.

Experiment 15
UJT Characteristics

Purpose

1. To demonstrate the operation of a unijunction transistor.
2. To measure some of the characteristics of UJTs.
3. To demonstrate a practical application for the UJT.

Introduction

Experiment 15 is located in Blocks 15 I and 15 II on the right side of Circuit Board #2 as shown in Figure E15-1. All jumper locations mentioned in this experiment will refer to this block or to the Circuit Board's Interface Panel.

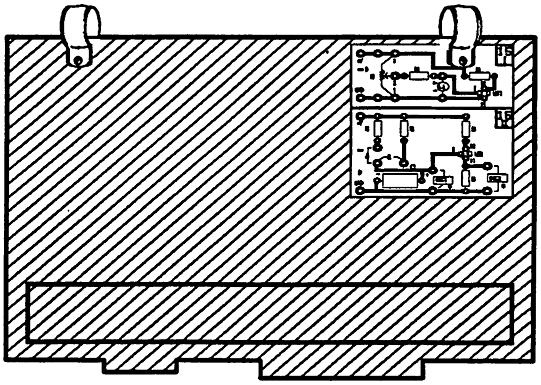


Figure E15-1
Blocks 15 I and 15 II of Circuit Board #2.

In the first part of this experiment, you will determine the peak voltage (V_P) and valley voltage (V_V) values for a typical UJT, and you will use the V_P value that you obtained to determine the UJT's intrinsic stand off ratio. In the second part of this experiment, you will demonstrate the operation of a UJT as a relaxation oscillator.

Material Required

- 1 ETW-3600 Analog Trainer
- 1 ETW-3567 Accessory Backpack
- 1 ETB-6103
  - 1 Board #2
  - 1 Red jumper wire
  - 1 Black jumper wire
  - 3 Blue jumper wires
  - 1 White jumper wire
- 1 Dual-trace oscilloscope

Procedure

1. With the Trainer turned off, install Circuit Board #2. Make sure that Board #2 is OFF. Also make sure all Trainer controls are turned fully counterclockwise.

2. Refer to Figure E15-2. In Block 15 I, install the red and black jumper wires to connect the Panel's +DC and GND terminals to the block's +V and GND terminals. Install the three blue jumper wires to connect the Panel's 1 kΩ terminals to the 1 kΩ terminals of R1 in the block.

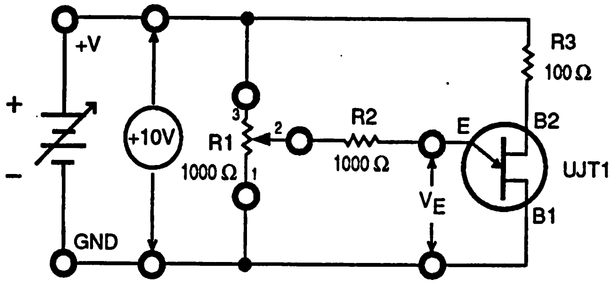


Figure E15-2
UJT experimental circuit.

3. Adjust the 1 kilohm potentiometer (R1) fully counterclockwise. Turn on your Trainer and Board #2. Adjust the Trainer's positive voltage control for +10 volts between +V and GND as shown in Figure E15-2. R1 is used to control the UJT's emitter-to-base 1 input voltage (V_E) with R2 serving as the series emitter resistor. Resistor R3 is used to prevent the base 1-to-base 2 current from exceeding a safe value without significantly affecting the normal operation of the circuit.

4. Connect the leads of your voltmeter between the UJT's emitter and base 1 terminals and measure the input voltage (V_E). Gradually turn R1 clockwise as you observe your meter. Continue to turn R1 until V_E reaches a peak value and decreases. Note the peak or maximum V_E value that you obtained. This maximum value of V_E represents the UJT's peak voltage (V_P). Since V_E drops suddenly after the V_P value is reached you may fail to detect the peak value the first time you perform this step. If that is the case, adjust the R1 fully counterclockwise, and start again. Record the V_P value that you obtained in the space provided below.

V_P = ______ volts

5. Continue to observe voltage V_E as you rotate R1 clockwise. Notice that once the V_P value is exceeded, voltage V_E rapidly drops to a low value and then increases by only a small amount. You will find that it is necessary to observe V_E very closely to detect this slight increase. The V_E value that you are observing (with R1 at minimum resistance) is approximately equal to the UJT's valley voltage (V_V). Record this V_V value in the space provided below.

V_V = ______ volts

6. Use the V_P value that you obtained in step 4 to determine the UJT's intrinsic standoff ratio (η). You will use the equation $V_P = \eta\,(V_{BB}) + V_F$ which can be rearranged to show that the intrinsic standoff ratio is equal to:

$$\eta = \frac{V_P - V_F\,.7}{V_{BB}\,10}$$

When using this equation remember that V_F is the forward voltage drop across the UJT's internal PN junction or approximately 0.7 volts and that V_{BB} is the voltage source which is 10 volts. Record your calculated value of η in the space provided below.

η = ______

7. Adjust R1 counterclockwise. Then, adjust the Trainer's + voltage control for +5 volts between +V and GND.

8. Repeat steps 4 and 5, and record the V_P and V_V values that you obtain in the spaces provided below.

V_P = ______ volts

V_V = ______ volts

9. Recalculate the UJT's intrinsic standoff ratio using the V_P value obtained in step 8 and the new V_{BB} value of 5 volts, and record your results below.

η = ______

10. Turn Board #2 OFF and remove all jumper wires.

Discussion

In this portion of the experiment, you measured the UJT's V_P and V_V values while the voltage source was equal to 10 volts. You should have obtained a V_P value that was approximately 8 volts. The V_V value that you obtained should have been equal to 2 volts, or less. This is a typical value for most UJT's.

Next, you used the V_P value to calculate the UJT's intrinsic standoff ratio. You should have obtained a ratio that was between 0.7 and 0.9, however, a slightly higher or lower ratio may have resulted. Your UJT is designed to have minimum ratio of 0.7 and a maximum ratio of 0.86, but minor errors in your voltage readings plus the assumption that V_F is always equal to 0.7 volts could cause the calculated ratio to be somewhat different than the true value.

Next, you adjusted the voltage source to 5 volts and again measured V_P and V_V. You should have discovered that the decrease in source voltage (V_{BB}) from 10 volts to 5 volts (a ratio of 2 to 1) caused the UJT's V_P value to decrease by an almost proportional amount. The decrease cannot be exactly proportional because of the constant voltage (0.7 volts) that is dropped across the UJT's internal PN junction. Therefore, your new V_P value was probably in the neighborhood of 4 volts or almost one-half of its previous value. Your new V_V value may have decreased slightly but no significant change should have been noticed. The V_V value tends to remain relatively constant in a UJT even when its V_{BB} value is varied over a considerable range.

You completed this portion of the experiment by using the new V_P value and the new V_{BB} value (5 volts) to calculate the UJT's intrinsic standoff ratio. You should have obtained approximately the same ratio as before, thus, proving that it remains essentially constant even though the operating voltage is changed. The intrinsic standoff ratio of any UJT has a fixed value that is determined by the internal resistances within the device. If you noticed any change, it was probably due to errors in voltage measurements and the assumption that V_F = 0.7 volts.

Procedure (Cont.)

11. Refer to the circuit shown in Figure E15-3. Use the red and black jumper wires to connect the + and GND terminals from the Panel to the +V and GND terminals in Block 15 II. Then install a white jumper wire at J2.

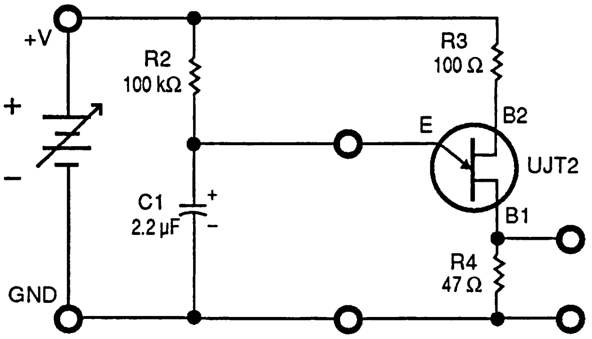


Figure E15-3
UJT relaxation oscillator circuit.

This circuit is basically identical to the UJT relaxation oscillator circuit shown in textbook Figure 8-22. However, resistor R1 (R2 in Fig. E15-3) has a fixed value and cannot be used to adjust the frequency of the circuit. The frequency is fixed at a low value so that one complete sawtooth or pulse waveform is produced approximately 3 times a second.

12. Turn on Board #2 and adjust the Trainer's + voltage control until +10 volts is applied to the circuit.

13. Measure the voltage across C1 with your oscilloscope. This voltage will gradually rise to a maximum value and then rapidly drop to a minimum value to produce a sawtooth waveform as shown in Figure 8-23A in the textbook. Note the maximum and minimum voltages and record them below.

maximum voltage = ______ volts

minimum voltage = ______ volts

14. Connect your other oscilloscope probe across R4. This voltage will occur in pulses as shown in Figure 8-23B in the textbook.

15. Switch Board #2 OFF. Remove the 100 kilohm resistor (R2) and in its place install a 10 kilohm resistor (R1) by moving the white jumper from J2 to J1. Then turn on Board #2.

16. Measure the voltage across C1 again with your oscilloscope. Observe the maximum and minimum voltage values and also note the frequency of the voltage fluctuations. Record the maximum and minimum values below. Is the frequency higher or lower than it was in step 13? ____________ .

maximum voltage = ______ volts

minimum voltage = ______ volts

17. Notice that the voltage difference between V_P and V_V is approximately equal to 60% of +V. And 60% of +V is about one time constant for C1 for each oscillation. Calculate the time constant of the 10 kilohm resistor and 2.2 μF capacitor. TC = ______ . The frequency of oscillation should be approximately the reciprocal of the time constant. Frequency = ______ . Now measure the period of the waveform and compare these values with your calculated values.

measured period = ______

measured frequency = ______

18. Turn off Board #2 and your Trainer. Remove all jumper wires.

Discussion

In this portion of the experiment, you used your oscilloscope to observe the operation of a UJT relaxation oscillator. The signal you observed should have resembled the signal shown in Figure 8-23A. The maximum voltage was equal to the UJT peak voltage (V_P). The V_P value was determined in step 4. Each time this V_P value is reached the UJT turns on and the voltage across C1 immediately drops to the UJT's valley voltage (V_V) value and causes the device to turn off.

When you monitored the voltage across R4 you should have observed voltage pulses that occurred each time the UJT turned on and allowed C1 to discharge through R4.

When you replaced the 100 kilohm resistor (R2) with a smaller 10 kilohm resistor and observed the voltage across C1, you should have obtained a maximum value close to V_P and a minimum value close to the V_V value. The frequency was higher because the lower value of R2 supplied more current to the capacitor making it charge more rapidly.

From step 17 you can see that the measured period and frequency is approximately equal to the calculated values. Differences are due primarily to the capacitor's tolerance and to the transistor's variations.

Summary

The UJT's important electrical characteristics occur between its emitter and base 1 leads. The device will turn on and conduct a substantial current through these leads when the voltage across these leads reaches a certain maximum value known as the peak voltage (V_P). Beyond this point the UJT exhibits a negative resistance until a certain minimum voltage known as the valley voltage (V_V) is reached. These characteristics allow the UJT to generate repetitive signal when used in a relaxation oscillator circuit.

Experiment 16
Introduction To Digital ICs

Purpose

1. To illustrate the concept of binary ones and zeroes.
2. To demonstrate the action of a typical NAND gate.
3. To demonstrate the complementary outputs of a digital device.

Introduction

Experiment 16 is located in Block 16 on the lower right side of Circuit Board #2 as shown in Figure E16-1. All jumper locations mentioned in this experiment will refer to this block or to the Circuit Board's Interface Panel.

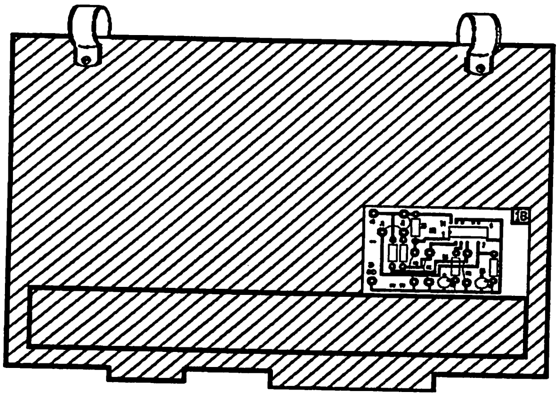


Figure E16-1
Block 16 of Circuit Board #2.

The purpose of this experiment is to demonstrate a digital IC in a typical application. A digital device has two discrete values of outputs. The output will either be binary one (1) or binary zero (0). The actual voltage value of the output is not important. The important thing is that the output can be identified as either a 1 or a 0. For this purpose you will use LEDs that, when lit, represent a digital logic one (binary one or 1) and, when out, represent a logic zero (binary zero or 0).

This experiment is only an introduction to digital devices and it contains some of the terms you will encounter as you continue your studies in digital electronics. Complete courses on digital techniques are also available from Heathkit Educational Systems. In the experiment the oscilloscope can be used in conjunction with the LEDs to see the high and low voltage levels that represent binary 1 and 0.

Material Required

1 ETW-3600 Analog Trainer
1 ETW-3567 Accessory Backpack
1 ETB-6103
    1 Board #2
    1 Red jumper wire
    1 Black jumper wire
    2 White jumper wires
    1 Green jumper wire
1 Dual-trace oscilloscope (optional)

Procedure

1. With the Trainer turned off, install Circuit Board #2. Make sure that Board #2 is OFF. Also make sure all Trainer controls are turned fully counterclockwise.

2. Refer to Figure E16-2. In Block 16, install the red and black jumper wires to connect the Panel's +5 and GND terminals to the block's +5 and GND terminals. Install a white jumper wire at J2. This is the circuit you'll be using in this part of the experiment.

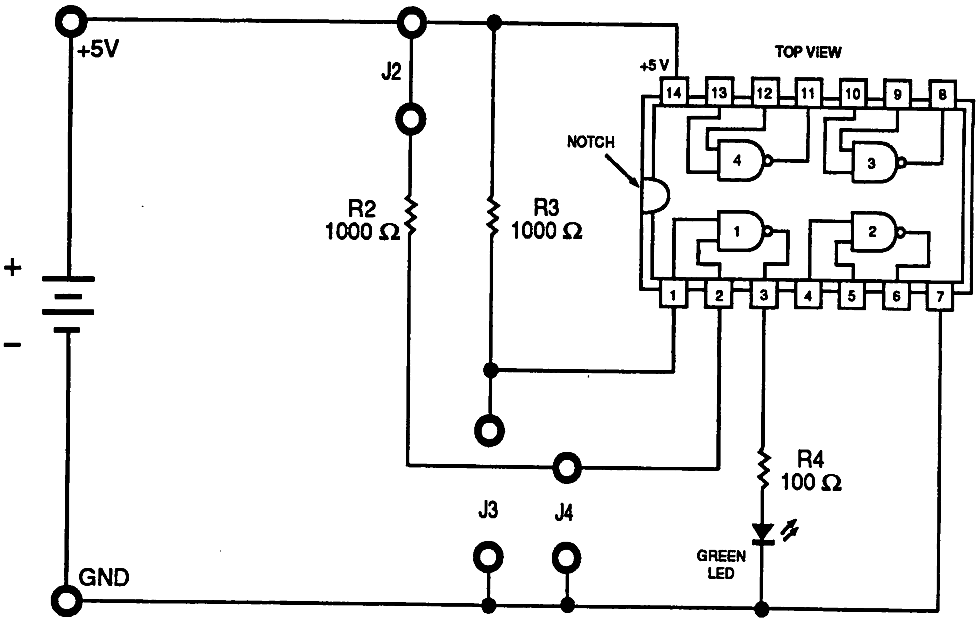


Figure E16-2
Circuit for step 2.

3. Turn the Trainer and Board #2 ON. Notice that +5 volts is applied to both inputs of the gate at pins 1 and 2 through resistors R2 and R3. Is the green LED on or off? ______. At this point, disregard the condition of the red LED.

4. Look at the truth table in Figure E16-3. Following to the table, apply +5 volts and ground (⏚) to pins 1 and 2. Fill in column 3 with the condition of the LED, either on or off. Since, in step 3, you have already applied +5 volts to both pins 1 and 2, enter your the condition of the LED in the table. To apply ground to pin 1, install a jumper wire at J3. To apply ground to pin 2, install a jumper wire at J4.

PINS		
1	2	LED
⏚	⏚	
⏚	5V	
5V	⏚	
5V	5V	

Figure E16-3
NAND gate truth table.

5. Turn Board #2 OFF and remove any jumper wires at J3 and J4. Refer to Figure E16-4. This is the circuit you'll be using in this next part of the experiment.

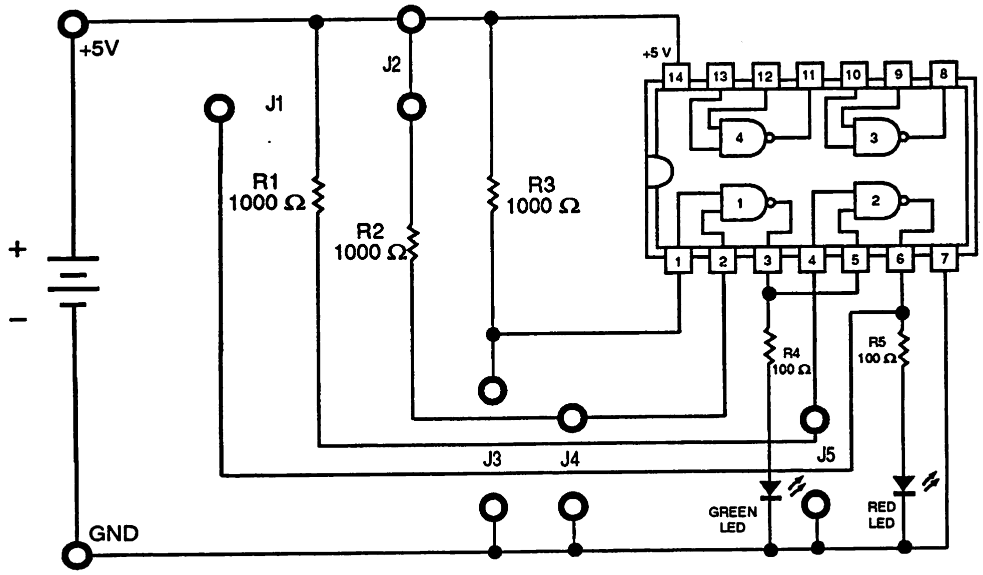


Figure E16-4
Dual inverter circuit.

6. Turn Board #2 ON and note the condition of the LEDs.

red LED ______ (on/off)

green LED ______ (on/off)

7. Install a jumper wire at J3. This connects ground to pin 1 of the IC. Note the condition of the LEDs.

red LED ______ (on/off)

green LED ______ (on/off)

8. Remove the jumper wire from J3. The green LED should have gone out and the red LED should have lit as soon as ground was removed and remained lit when the +5 volts was reapplied.

9. Switch Board #2 OFF and remove all jumper wires.

Discussion

In step 3 you connected the supply voltage to + 5 volts which is a common supply for digital circuits. Next, you should have recognized the truth table for the NAND gate. Ground is considered to be binary 0 and + 5 volts is a binary 1. Column 3 of Figure E16-3 should indicate that the LED was lit anytime that either input (pins 1 and 2) is grounded. This is exactly inverted from the AND gate truth table which provides a 1 in the output only when both inputs are 1. If in Figure E16-3, we substituted 0 for ground and 1 for 5V, a more recognizable truth table would result.

PINS		
1	2	LED
⏚	⏚	ON
⏚	5V	ON
5V	⏚	ON
5V	5V	OFF

or

PINS		
1	2	LED
0	0	1
0	1	1
1	0	1
1	1	0

In step 5 the circuit is connected as 2 inverters. Note that the LEDs are connected to different output pins. The red LED identifies what is called the "output" and the green LED identifies the "complementary output." You should notice that both LEDs are **not lit** at the same time. They are complements of each other.

Initially the red LED should be lit. R1, R2, and R3 ensure that the gate inputs are 1's when jumpers are removed from the circuit. When a ground was applied to the inputs the red LED should have gone out and the green LED should have turned on. With a 0 into the first gate its output (pin 3) should have gone high thus the green LED should have turned on. This high is applied to the input (pin 5) of the second gate. And, with the 5 volts already applied to the other input at pin 4, it produces a low at the output (pin 6) of the second inverter. A low (0) out is represented by the red LED being turned off. Looking back at the NAND truth table we find that indeed, with a high (1) at both gates, the result is a low (0) output.

Procedure (Cont.)

10. Switch Board #2 OFF. Install a white jumper wire at J1. This connects the output of the second gate at pin 6 to the input of the first gate at pin 2. This is shown in Figure E16-5.

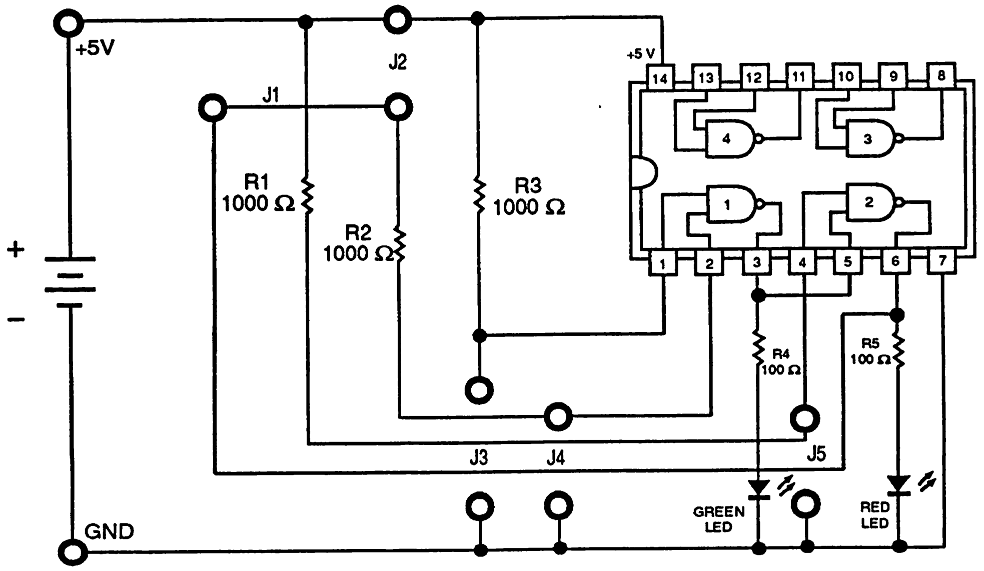


Figure E16-5
Circuit for step 10.

11. Switch Board #2 ON. Install a jumper wire at J5 to ground pin 4 of the IC. This connection can be removed as soon as a connection has been made. Note the condition of the LEDs and then remove the jumper wire.

red LED ______ (on/off)

green LED ______ (on/off)

12. Momentarily reinstall the jumper at J5. This should not have any effect on the circuit. Try it, did the LEDs change? ______ (yes/no).

13. Now install a jumper wire at J3. This applies a ground to pin 1 of the IC. Note the results below.

red LED ______ (on/off)

green LED ______ (on/off)

14. Remove J3 and then momentarily reinstall it. There should have been no change in the LEDs. Now alternately install a jumper wire at J5 and then at J3. Note the response of the LEDs as you alternately ground pins 4 and 1.

pin 4 grounded ______ LED was lit

pin 1 grounded ______ LED was lit

15. Install a jumper wire at J5 to ground pin 4 of the IC. Now momentarily install another jumper wire at J3 to ground pin 1 of the IC. Which LED is constantly lit with pin 4 grounded? Does this LED change states when pin 1 is grounded?

pin 4 grounded ______ LED is constantly lit

LED ______ (does/does not) change by grounding pin 1

16. Install a jumper wire at J3 to ground pin 1 of the IC. Now momentarily install another jumper wire at J5 to ground pin 4 of the IC. Which LED is constantly lit with pin 1 grounded? Does this LED change states when pin 4 is grounded?

pin 1 grounded ______ LED is constantly lit

LED ______ (does/does not) change by grounding pin 4

17. This completes the experiment. Turn Board #2 and the Trainer off, remove all jumper wires, and read the following discussion.

Discussion

In step 11 the red LED should have been lit and that indicates that the output of the digital device is a 1. This is sometimes referred to as storing a one. The circuit configuration is called a set/reset device. In this case, for our purposes, we define a lit red LED to indicate a set condition. Since the red LED is lit without applying an external pulse the set state is considered to be the static condition of the circuit. When the green LED is lit, then the device will be considered to be in the reset condition.

Pulsing the same pin (1 or 4) more than once will have no effect on the circuit. Once the circuit is (set or reset) it can only change to its complementary state. This is accomplished by alternately pulsing pins 1 and 4.

In step 15 you programmed the output (pin 6) of the set/reset device to be in the set condition (red LED lit) by grounding pin 4 (0). Then you pulsed the input to the first gate at pin 1. However, the circuit remained set (red LED lit) because pin 4 was still grounded. Of course, the green LED lit up when you applied a ground at pin 1. That's because a ground applied to an input of the first gate resulted in a high (1) at its output (lighting the green LED) at pin 3. However, the green LED does not remain lit after removing the ground because the set/reset device is latched into its set state (red LED lit with pin 4 grounded). When pin 4 is allowed to return to a logic 1 (high), the red LED will stay lit because the circuit remembers the last input which went from a 0 to a 1.

In step 16 the opposite condition was programmed. The digital device was latched into the reset state (pin 1 grounded). Applying a ground pulse to pin 4 caused the set output (red LED) to momentarily go high. However, the reset output (green LED) remained high after removing the ground from pin 4.

The conditions of set and reset and ones and zeroes are the basics of most digital equipment. This you will see and understand as you continue your study of electronic circuits and digital techniques.

Summary

In this experiment, you demonstrated a typical application of a digital IC. You saw that the digital device had two discrete values of outputs. The output was either a binary one or binary zero. The actual voltage value of the output was not important. The important thing is that the output can be identified as either a 1 or a 0. For this experiment the LEDs represented a digital logic 1 when lit. From the schematics, you noted that the LEDs are connected to different output pins. The red LED identified the "output" and the green LED identified the "complementary output" when the circuit was configured as a set/reset flip-flop.

Experiment 17
Operational Amplifiers

Purpose

1. To analyze some of the characteristics of a basic operational amplifier.
2. To analyze the operational amplifier as an inverting and noninverting amplifier.
3. To analyze the operational amplifier in the open and closed loop circuit configurations.
4. To analyze the operational amplifier in the voltage follower circuit configuration.

Introduction

Experiment 17 is located in Blocks 17 I III, 17 II, 17 IV, and 17 V. These blocks are located on the left and middle of Circuit Board #3 as shown in Figure E17-1. All jumper locations mentioned in this experiment will refer to this block or to the Circuit Board's Interface Panel.

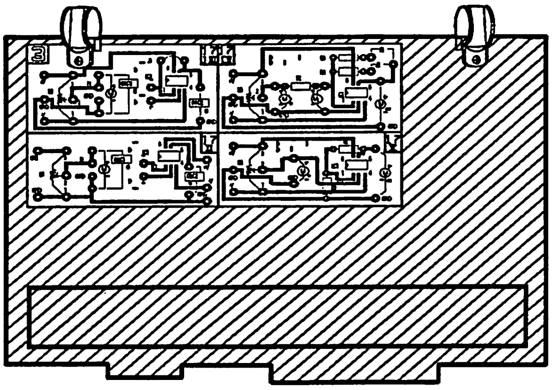


Figure E17-1
Blocks 17 I III, 17 II, 17 IV,
and 17 V of Circuit Board #2.

In this experiment you will analyze the operational amplifier (op amp) in a variety of circuit configurations: the basic comparator, inverting and noninverting amplifiers, gain amplifiers, and a particular configuration that is called a voltage follower. They can all be constructed using the basic op amp and a few discrete components. The op amp is considered to be the basic linear IC.

Material Required

1	ETW-3600 Analog Trainer
1	ETW-3567 Accessory Backpack
1	ETB-6103
	1 Board #3
	1 Red jumper wire
	1 Black jumper wire
	1 Green jumper wire
	2 White jumper wires
	3 Blue jumper wires
	1 Yellow jumper wire
	3 Orange jumper wires
1	Dual-trace oscilloscope

Procedure

1. With the Trainer turned off, install Circuit Board #3. Make sure that Board #3 is OFF. Also make sure all Trainer controls are turned fully counterclockwise.

2. Refer to Figure E17-2. Install one end of the red, black, and green jumper wires at the Interface Panel's +, –, and GND terminals. Install the other end of these jumper wires to the +V, –V, and GND terminals in Block 17 I III. Use the three blue jumper wires to connect the Panel's 1 kΩ potentiometer terminals to the R1 terminals in the block. And last, install the two white jumper wires. Install one jumper between the IN and the – terminal that goes to pin 2 of the IC. Install the other jumper between GND and the + terminal that goes to pin 3 of the IC.

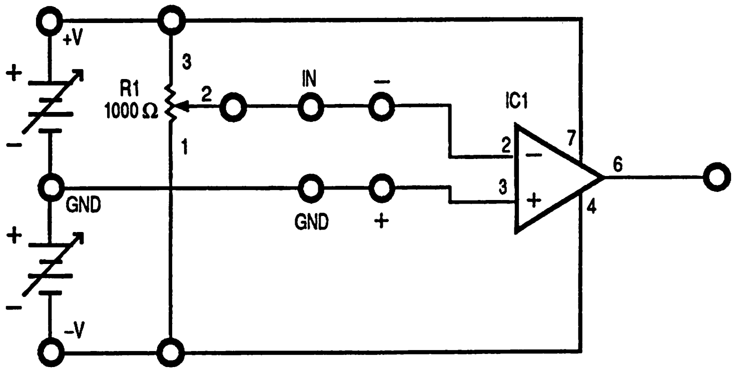


Figure E17-2
Basic op amp.

3. On the Trainer, center R1. Set the Trainer's positive and negative DC power supply controls fully clockwise. Connect your meter to terminal 2 of R1 (V). Switch the Trainer and Board #3 ON. Readjust R1 for zero volts at terminal 2. Switch Board #3 OFF and set your oscilloscope controls to:

   Trigger mode to DC

   Ch. Y1 V/cm to 5V and DC coupling

   Ch. Y2 V/cm to 5V and DC coupling

   Connect ch. Y1 to the IN terminal (op amp pin 2)

   Connect ch. Y2 to pin 6 of the op amp

4. Switch Board #3 ON and, if necessary, readjust R1 for a zero reading on your meter. From the scope, read and record the voltage measured at the op amp's output (pin 6).

   ch. Y2 = ______ volts

5. Adjust R1 until ch. Y2 indicates zero volts. Record the voltage measured at the input of the op amp (pin 2). If you cannot zero the output, adjust R1 until the output display (ch. Y2) alternates above and below the zero reference line with very small adjustments of R1.

   ch. Y1 = ______ volts

6. Again adjust R1 for 0 volts DC. Now rotate R1 fully clockwise and note if the input and output displays are above (positive) or below (negative) their zero reference lines. Record your results below.

input (pos/neg) ____________

output (pos/neg) ____________

7. Rotate R1 fully counterclockwise. Again note if the input and output displays are above (positive) or below (negative) their zero reference lines. Record your results below.

input (pos/neg) ____________

output (pos/neg) ____________

8. Switch Board #3 OFF and reverse the connections to pins 2 and 3 of the op amp. At this time pin 2 should be grounded and pin 3 should be connected to the center terminal of R1. Switch Board #3 ON and repeat steps 4, 5, 6, and 7 and record the following:

step 4 ch Y2 = ______ volts

step 5 = ______ volts

step 6 input (pos/neg) ____________

output (pos/neg) ____________

step 7 input (pos/neg) ____________

output (pos/neg) ____________

Switch Board #3 OFF and remove all jumper wires.

Discussion

You probably did not get both the input and output zeroed, if you did, you are to be congratulated. If you zeroed both the input and output then you have an excellent lab station and you also have an op amp that is perfectly balanced. The op amp in the open loop circuit configuration using DC voltages has an almost infinite gain. The slightest variation at the input could cause the op amp to saturate (that is, the output will go to maximum voltage in either the positive or negative direction). The very small 60 cycle ripple from the power supply is usually enough to drive the op amp between negative and positive saturation values. What you should have realized from this experiment is that the op amp saturates at a value slightly less (usually about 2 volts) than the supply voltages. The fact that the op amp saturated with a very small input voltage proves that the op amp is a very high gain DC amplifier.

You should have noticed in steps 4 through 7 that the input and output waveforms are 180 degrees out of phase (inverted). As the input went positive the output saturated in the negative direction and when the input went negative the output saturated in the positive direction.

In step 8 when the input was switched from pin 2 to pin 3 the most noticeable change was that the output followed the input (noninverted). Your other readings in step 8 should have approximated the values obtained in steps 4, 5, 6, and 7.

Procedure (Cont.)

9. Refer to the circuit shown in Figure E17-3. Use the red, green, and black jumper wires to connect the positive and negative power supplies from the Panel to Block 17 II. Use the yellow jumper wire to connect the Panel's SINE terminal to the SINE terminal in the block. Use the three orange jumper wires to connect the Panel's 100 kΩ terminals to R1. Then use the two white jumper wires to connect block terminals IN to – and GND to +.

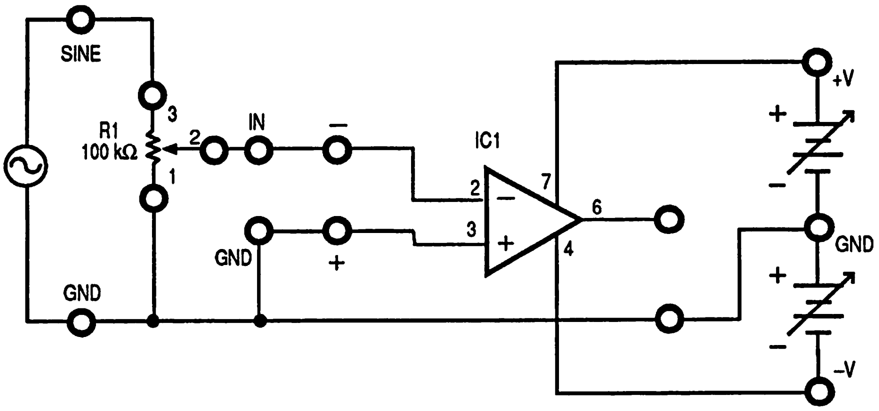


Figure E17-3
Op amp used as an amplifier.

10. On the Trainer, set the generator to the 1× position and the generator control to 200 Hz. Rotate R1 (100 kΩ) to its midway position. Switch Board #3 ON and set the Trainer's positive and negative power supply controls to fully clockwise.

11. Connect the scope's Y1 probe to the input of IC1 and the Y2 probe to the output. Switch the board on and observe the input and output displays. Note that with an AC signal the gain is still very high and when pin 2 is used as the input, the input and outputs are out of phase (polarity inversion). If possible, decrease the input signal until the output signal just starts to decrease. Record the input and output voltage below and calculate the voltage gain.

V_{in} = ______

V_{out} = ______

A_V = ______

12. Switch Board #3 OFF and reverse the connections to pins 2 and 3. Switch Board #3 ON and note the input and output waveforms. The most noticeable effect is that the input and output are again in phase with each other.

13. Set the generator range switch to the 10× position and the control to 20 kHz. Slowly increase the input signal amplitude by turning control R1 clockwise. Note that the op amp does not react the same to an AC signal as it does to a DC signal. Try several frequencies between 200 Hz and 20 kHz and observe the gain differences at the various frequencies. Switch Board #3 OFF, remove all jumper wires, and read the following discussion.

Discussion

In steps 11 and 12 you should have seen that the op amp can amplify AC signals and that it was still capable of inversion (– input) or noninversion (+ input). The op amp's gain should have decreased as frequency increased. The op amp has a gain bandwidth product of approximately 1 MHz. Even with this basic circuit you could see that the gain characteristics were drastically reduced when the frequency was increased. Some of the distortion that you noticed in the AC output was due to the internal capacitance and noise in the Trainer and the op amp.

Procedure (Cont.)

14. Refer to Figure E17-4 and go to Block 17 I III. Use the red, green, black, orange, and white jumper wires to configure the circuit as shown. (Do not install a jumper at J1.) Connect ch. Y1 of the oscilloscope to the input (pin 2) and ch. Y2 to the output (pin 6) of the op amp. Switch Board #3 ON and set the Trainer's positive and negative DC power supply controls fully clockwise. Set the voltage at terminal 2 of R1 to zero volts. Note that the output is close to one of the supply voltages. Switch Board #3 OFF. Connect a jumper wire at J1 between pin 6 (output) and pin 2 (inverting input). Switch Board #3 ON and note the output display on ch. Y2 of your oscilloscope. Record your measurements below:

ch. Y2 output without jumper = ______ volts

ch. Y2 output with jumper = ______ volts

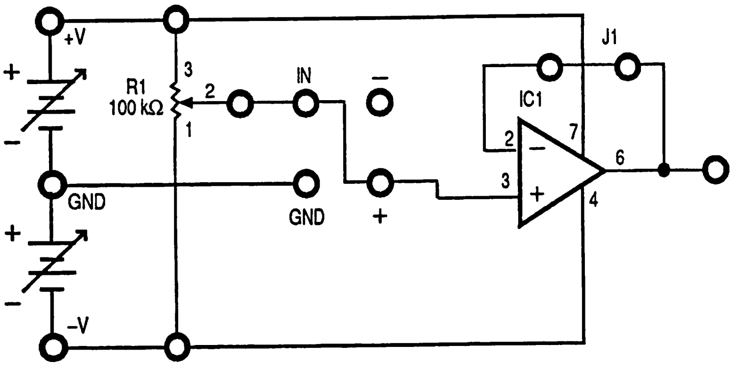


Figure E17-4
Op amp operating in the closed loop mode.

15. Zero your displays (chs. Y1 and Y2) across the center of your oscilloscope. Adjust R1 until you are reading +6 volts on terminal 2 of R1. Record the input and output voltages below:

V_{in} = ______

V_{out} = ______

16. Adjust R1 for +8 V, +10 V, −6 V, −8 V, −10 V and record the corresponding outputs below:

inputs of	+8 V	+10 V	−6 V	−8 V	−10 V
outputs are	______	______	______	______	______

Switch Board #3 OFF and remove all jumper wires from Block 17 I III.

17. Refer to Figure E17-5 while installing the following jumper wires from the Panel to Block 17 IV.

JUMPER WIRE(S)	FROM PANEL	TO BLOCK
RED	+DC	+V
GREEN	−DC	−V
BLACK	GND	GND
ORANGE	100 kΩ	R1

Also install a white jumper wire at J1. This places a 100 kilohm resistor (R3) between pin 6 and pin 2 of the IC. Also notice that there is now a 10 kilohm resistor in series between terminal 2 of R1 and pin 2 of the op amp.

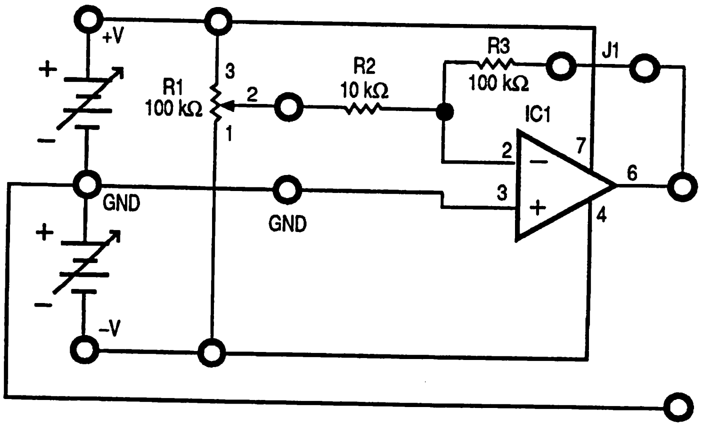


Figure E17-5
Circuit for step 17.

18. Switch Board #3 ON and adjust R1 for an input voltage (V_{IN}) of +0.5 volts. Record the output voltage (V_{OUT}) below: and then calculate the voltage gain (A_V).

0.5 volts input provides ______ output volts.

$$A_V = \frac{V_{out}}{V_{in}} = \underline{\hspace{3cm}}$$

19. On your scope, set ch Y1 to 0.5V/cm and ch Y2 to 5V/cm. Set both channels to DC coupling and center both traces in the display. Connect the Y1 probe to measure the input (pin 2) of IC1 and the Y2 probe to measure the output (pin 6). Vary R1 and note the movement of the two traces. Notice that the voltage at pin 2 is "zero" as long as the output remains within the normal operating voltage range of the op amp. This voltage is between +12 volts and –12 volts. As soon as the output tries to go above +12V or below –12V, the Y1 trace moves from "zero." This point is called a *virtual ground* because the voltage does not change as long as the op amp is operating within its limits.

20. Switch Board #3 OFF. Remove the jumper from J1 and install it at J2. This replaces the 100 kilohm resistor with a 10 kilohm resistor. Switch Board #3 ON and answer the following.

0.5 volt input provides ______ volts output

Calculate the voltage gain (A_V):

$$A_V = \frac{V_{out}}{V_{in}} = \underline{\hspace{3cm}}$$

21. Switch Board #3 OFF and remove all jumper wires from Block 17 IV.

22. Refer to Figure E17-6 while installing the following jumper wires from the Panel to Block 17 V.

JUMPER WIRE(S)	FROM PANEL	TO BLOCK
RED	+DC	+V
GREEN	−DC	−V
BLACK	GND	GND
ORANGE	100 kΩ	R1

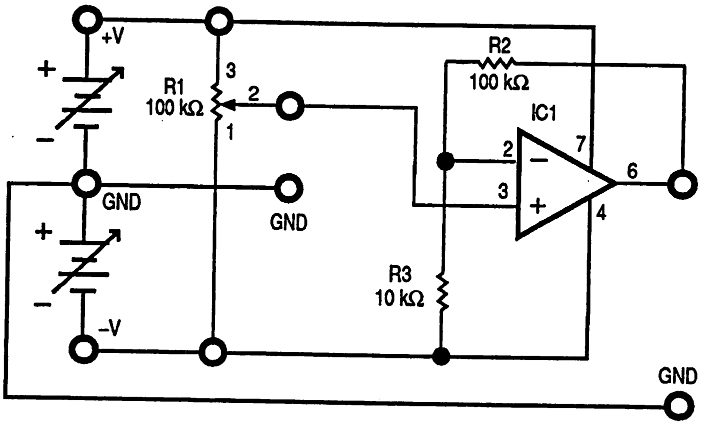


Figure E17-6
Circuit for step 19.

23. Switch Board #3 ON and answer the following questions.

does the circuit invert? ______

is the gain higher or lower than step 18? ______

approximately how much higher? ______

24. Switch Board #3 and the Trainer OFF. Remove all jumper wires and proceed to the following discussion.

Discussion and Summary

In step 14, you constructed a noninverting amplifier with a variable DC input. Next, you zeroed the input voltage and observed that the output voltage was approximately equal to one of the supply voltages. Then you installed a jumper wire between pins 2 and 6 and observed that the gain of the circuit was +1. You proved this by measuring the output at several input voltages.

In steps 17 through 20, you proved that the op amp can be operated with gains other than 1. The actual gain can be controlled by changing the ratio of the feedback resistor to the input resistor. When the feedback resistor was 100 kilohms and the input resistor was 10 kilohms and pin 2 was used as the input, the gain was –10. Here the ratio of feedback resistor to input resistor was 10 to 1, the same as the gain. When you replaced the 100 kilohm resistor with a 10 kilohm resistor, the ratio was reduced to 1 to 1. This was reflected in a reduced gain which you should have calculated to be –1.

When, in step 19, you measured the DC voltage at the inverting input, you saw that it appeared to be zero even though there was a measurable input and output signal. This point is called a "virtual ground." From your textbook, recall that an op amp has an almost infinite gain. If the gain of the IC is infinite, then for an output to be less than ±12 volts, the ± input must be very small. Since the + input of the IC is grounded, the – input also appears grounded, thereby appearing as a virtual ground. As a result all of the input current passes through R2 and R3. Since the right end of R2 appears grounded (virtual ground), the input impedance equals R2. This means a designer can set up a precise value of input impedance as well as voltage gain.

In step 23, the circuit did not invert because the input was applied to the noninverting input at pin 3. And the gain was approximately 11 times. In this configuration the gain can be calculated as $A_V = (R2 + R3)/R3 = (100\ k\Omega + 10\ k\Omega)/10\ k\Omega = 11$.

Experiment 18

Phototransistor Characteristics

Purpose

1. To demonstrate the operation of a phototransistor.
2. To measure some of the important characteristics of light sensitive devices.

Introduction

Experiment 18 is located in Block 18 in the upper right of Circuit Board #3 as shown in Figure E18-1. All jumper locations mentioned in this experiment will refer to this block or to the Circuit Board's Interface Panel.

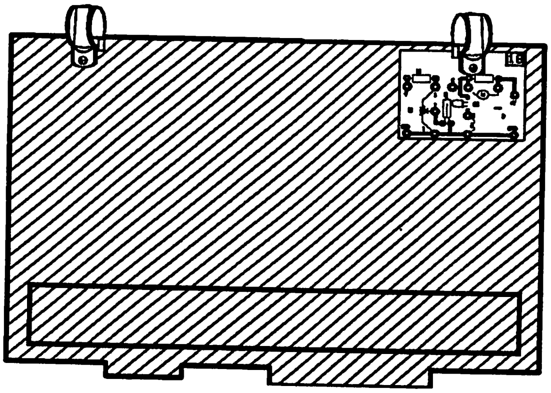


Figure E18-1
Block 18 of Circuit Board #3.

In this experiment, you will demonstrate how the phototransistor controls the current flowing through a load resistance in accordance with light intensity.

Material Required

- 1 ETW-3600 Analog Trainer
- 1 ETW-3567 Accessory Backpack
- 1 ETB-6103
  - 1 Board #3
  - 1 Red jumper wire
  - 1 Black jumper wire
  - 1 Green jumper wire
  - 1 White jumper wire
  - 3 Blue jumper wire

Procedure

1. Refer to Figure E18-2 while installing the red, black, green, and blue jumper wires between the Panel and Block 18. Use these jumper wires to connect + and – DC voltage, GND, and the 1 kΩ potentiometer. Install the white jumper wire at J1. In this portion of the experiment you will use the 1 kilohm potentiometer (R2) to adjust the voltage applied to the lamp and therefore control its brightness. The phototransistor (Q1) is positioned so that it will respond to the light produced by the lamp. In turn, Q1 will control the current through the 1 kilohm resistor (R3).

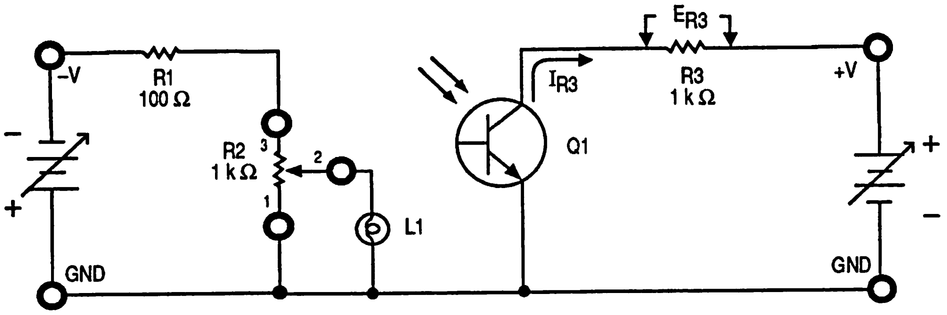


Figure E18-2
Experimental light sensitive circuit.

2. Adjust potentiometer R2 fully counterclockwise and then, turn on your Trainer and Board #3. Adjust the Trainer's + voltage control for 2 volts and the – voltage control fully counterclockwise.

3. Measure the voltage across R3. While taking this measurement, place your hand or some other object over the phototransistor to shield it from ambient room light. Try to reduce the light level to an absolute minimum. Record your measured voltage in the E_{R3} row of the +2V column in the chart of Figure E18-3. Your recorded value represents the voltage across R3 when the light intensity is essentially zero. Next, use your recorded voltage drop across R3 and the value of the resistance of R3 and determine the current through R3. Record your calculated current value in the I_{R3} row in the +2V column of Figure E18-3. If your E_{R3} and I_{R3} values are too low to accurately measure simply record a zero in the respective column in Figure E18-3.

NO LIGHT						
+V	2	4	6	8	10	12
E_{R3}						
I_{R3}						

Figure E18-3
Record of output load currents
and voltages for step 3.

4. Now repeat step 6 for the remaining values of +V. Fill in the chart for the corresponding values of E_{R3} and I_{R3} with the phototransistor shielded from light.

5. Now remove the shield from the phototransistor and measure the voltage dropped across R3 using the same +V voltages from steps 3 and 4. Fill in the results of your measurements of E_{R3} and calculations of I_{R3} in the chart in Figure E18-4.

NORMAL ROOM LIGHT						
+V	2	4	6	8	10	12
E_{R3}						
I_{R3}						

Figure E18-4
Record of output load currents
and voltages for step 5.

6. On the Trainer, rotate the – power supply control fully clockwise. Return the Trainer's + power supply output to +2 volts. Connect your meter across R3. Slowly rotate R2 clockwise until the lamp begins to glow and the voltage across R3 begins to increase. Measure the voltage across R3 and then calculate the current flowing through the resistor. Enter these values in the appropriate spaces in the chart in Figure E18-5. Increase +V to the values in the chart and complete the chart in Figure E18-5.

LOW LAMP LIGHT						
+V	2	4	6	8	10	12
E_{R3}						
I_{R3}						

Figure E18-5
Record of output load currents
and voltages for step 6.

7. Rotate R2 fully clockwise for full lamp brightness. Repeat the voltage measurements and current calculations for R3 for the values of +V in the chart of Figure E18-6. Fill in the appropriate spaces in the chart.

FULL LAMP LIGHT						
+V	2	4	6	8	10	12
E_{R3}						
I_{R3}						

Figure E18-6
Record of output load currents
and voltages for step 7.

8. Now position R2 midway between full lamp brightness and the point where the lamp was just glowing as in step 6. Repeat step 7 and fill in the chart in Figure E18-7.

HALF LAMP LIGHT						
+V	2	4	6	8	10	12
E_{R3}						
I_{R3}						

Figure E18-7
Record of output load currents
and voltages for step 8.

9. Use the corresponding values of E_{R3} and I_{R3} that you recorded in steps 1 through 8, and plot them on the graph shown in Figure E18-8. Connect the various points plotted to form continuous curves. Label each curve with the amount of light used.

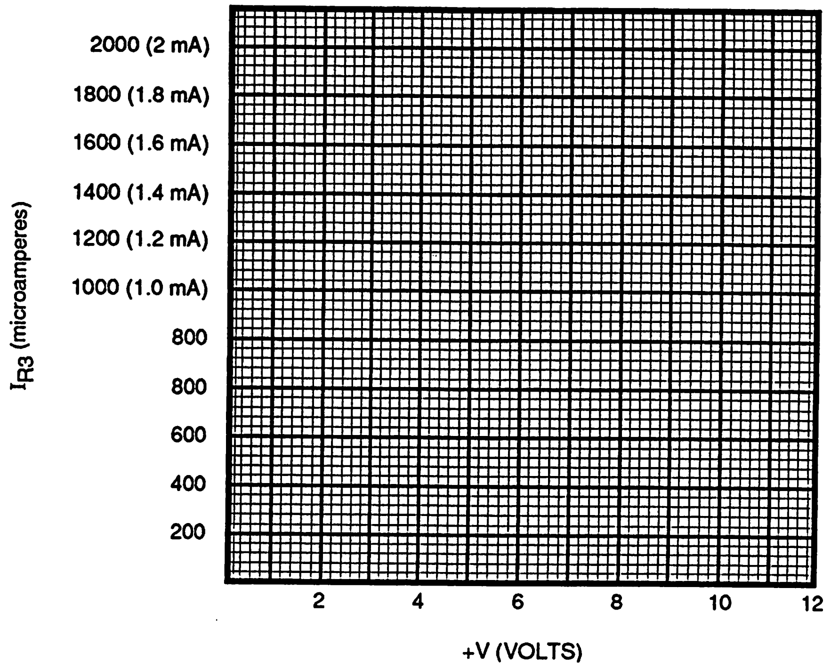


Figure E18-8
Graph for step 9.

Discussion

In this portion of the experiment, you demonstrated how a phototransistor varies its conduction according to the light intensity, and controls the amount of current applied to a load resistance (R3). First you shielded the phototransistor from light and determined the voltage dropped across the load and the current through the load. You found that the voltage across the load was very low at this time. It may have been only one or two hundredths of a volt, or it could have been too low to accurately measure, in any case, it would be effectively zero. When you used this voltage value to determine current flow, you should have obtained a very low current value. It may have been as low as 0.002 milliamperes (2 microamperes) or lower. If your phototransistor was adequately shielded, this current value will be approximately equal to the phototransistor's dark current value. An extremely low dark current is the mark of a good phototransistor.

Next, you observed the current through the load increased as you increased the voltage applied to the lamp. As the lamp became brighter, you noticed that the voltage across the load increased in proportion to light intensity. When the light was fully on, you recorded the voltage dropped across R3 and calculated the current flowing through R3 to be about 1 to 2 mA. This voltage will vary from trainer to trainer. You also noticed that the output current remained fairly constant with changes to +V. The graph that you drew should look very similar to the graph you drew for the common-emitter amplifier in Experiment 7. The big difference is that, instead of changing the base current (I_B) for each curve, you changed the light level.

Summary

In this experiment you demonstrated how the phototransistor controls current flow through a load resistance in accordance with light intensity. First you measured the voltage drop across a load resistor. Then you calculated the current through it. You saw that different light levels produced different current amounts through the phototransistor and hence the load. You also noticed that the output characteristics are similar to a common-emitter amplifier. The phototransistor acts as a constant current source that is dependent on a light level instead of a voltage or current.

Experiment 19
LED Characteristics

Purpose

1. To demonstrate the operation of a typical LED.
2. To measure some of the characteristics of the LED.
3. Identify the LED's anode and emitter (cathode).

Introduction

Experiment 19 is located in Block 19 in the middle right of Circuit Board #3 as shown in Figure E19-1. All jumper locations mentioned in this experiment will refer to this block or to the Circuit Board's Interface Panel.

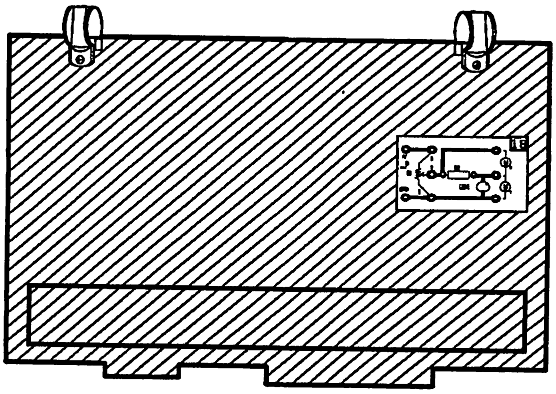


Figure E19-1
Block 19 of Circuit Board #3.

In this experiment, you will observe the operation of a typical GaAsP LED which emits a visible red light. You will observe the relationship between the LED's forward current and forward voltage as you observe the LED's brightness.

Material Required

1 ETW-3600 Analog Trainer
1 ETW-3567 Accessory Backpack
1 ETB-6103
    1 Board #3
    1 Red jumper wire
    1 Black jumper wire
    3 Blue jumper wires

Procedure

1. With the Trainer turned off, install Circuit Board #3. Make sure that Board #3 is OFF. Also make sure all Trainer controls are turned fully counterclockwise.

2. With Board #3 installed in the Trainer, examine the red LED in Block 19. Notice that the LED has a flat side which identifies its cathode lead. Remember, a diode (which also includes LEDs) is forward biased when its cathode is negative in respect to its anode and a forward biased diode has a lower resistance than a reverse biased diode.

3. Now, install the red, black, and blue jumper wires between the Panel and Block 19 to complete the circuit shown in Figure E19-2. Adjust potentiometer R1 fully counterclockwise. R1 will be used to control the voltage applied to the LED and its series 1 kilohm resistor (R2).

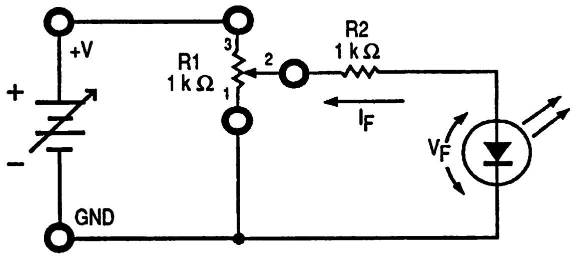


Figure E19-2
Experimental LED circuit.

4. Switch your Trainer and Board #3 ON. Adjust the + voltage control for +14 volts across R1.

5. Now adjust R1 until the voltage across R2 (V_{IF}) is equal to 1 volt. Since R2 has a value of 1 kilohm the current through it will equal:

$$I = \frac{1 \text{ volt}}{1000 \text{ ohms}} = 1 \text{ milliampere}$$

   Since this same current (series circuit) is flowing through the LED, the LED's forward current (I_F) must now be equal to 1 milliampere.

   As you continue this experiment, you will increase the input voltage and observe the voltage across the LED and the current flowing through it. As you perform the following steps, be sure to notice the variation in the LED's brightness.

6. Measure the forward voltage (V_F) across the LED. Record your measured value (in volts) immediately below the I_F value of 1 milliampere in the table provided in Figure E19-3. Your recorded value indicates the amount of forward voltage (V_F) across the LED when its forward current (I_F) is equal to 1 milliampere.

LED CURRENT-VOLTAGE MEASUREMENTS										
I_F (MILLIAMPERES)	1	2	3	4	5	6	7	8	9	10
V_F (VOLTS)										

Figure E19-3
Record of I_F and V_F values.

7. Complete the table in Figure E19-3 by determining the V_F value that corresponds to each I_F value listed. To do this, simply repeat steps 5 and 6 for each I_F value given. Remember to adjust the voltage across R2 to 2, 3, and 4 volts, etc., to obtain I_F values of 2, 3, or 4 milliamperes, respectively.

8. Plot the corresponding I_F and V_F values in Figure E19-3 on the graph shown in Figure E19-4. Connect the points to form a continuous curve. Switch Board #3 and your Trainer OFF.

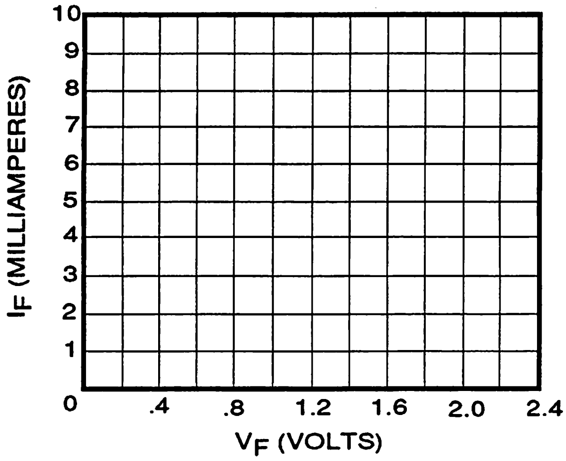


Figure E19-4
Graph for plotting I_F and V_F values.

Discussion

In this part of the experiment, you gradually increased the forward current (I_F) through the LED and determined its forward voltage (V_F) at intermediate points. Then you plotted a curve which effectively shows the relationship between I_F and V_F. Your curve should show that V_F remains relatively constant but does increase slightly as I_F increases. Your V_F values probably started at some value between 1.5 and 2 volts and increased to a few tenths of a volt as I_F increased to its maximum value. The exact V_F values are not important, but your curve should have the same general shape as the one shown in Figure 10-21 of the textbook. It should rise rapidly showing that V_F is essentially constant with changes in I_F. The lower portion of your curve (between 0 and 1 milliampere) was not plotted due to the difficulty in measuring these very small currents. This portion of the curve rises slowly at first and then rapidly as shown in Figure 10-21 in the textbook. Your V_F measurements are significant because they indicate the typical voltages that you would expect across an LED operating within its normal range of I_F values.

Each time you increased I_F to a higher value, you should have noticed an increase in the intensity of the light produced by the LED. The radiant power produced by the LED increased with current.

Summary

In this experiment, you observed the operation of a typical LED that emits a visible red light. You observed the relationship between the LED's forward current and forward voltage. You found that forward voltage (V_F) remains relatively constant while forward current (I_F) can vary over its entire range. However, as I_F increased, so did the brightness of the LED.

Experiment 20
Combining Solid State Components

Purpose

1. To use the 3 basic types of solid state components in a circuit.
2. To demonstrate a basic function of each in a combination circuit.
3. To set up and trouble shoot a basic combination circuit.

Introduction

Experiment 20 is located in Block 20 at the bottom of Circuit Board #3 as shown in Figure E20-1. All jumper locations mentioned in this experiment will refer to this block or to the Circuit Board's Interface Panel.

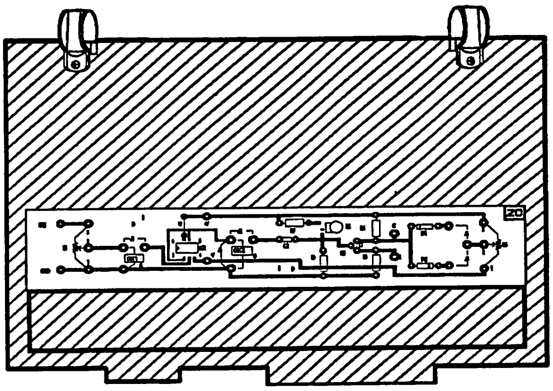


Figure E20-1
Block 20 of Circuit Board #3.

In this experiment, you will combine an integrated solid state chip, a transistor, and diodes into an electronic circuit. First you use test equipment to test each section of the circuit. Then you will combine the individual circuits into a combination circuit with a single input and output.

Material Required

1	ETW-3600 Analog Trainer
1	ETW-3567 Accessory Backpack
1	ETB-6103
1	Board #3
1	Red jumper wire
1	Black jumper wire
1	Yellow jumper wire
4	White jumper wires
3	Blue jumper wires
3	Orange jumper wires
1	Dual-trace oscilloscope

Procedure

1. With the Trainer turned off, install Circuit Board #3. Make sure that Board #3 is OFF. Also make sure all Trainer controls are turned fully counterclockwise.

2. Install the following jumper wires between the listed Panel and Block 20 terminals for the circuit shown in Figure E20-2.

JUMPER WIRE(S)	PANEL	BLOCK 20
YELLOW	SINE	SINE
BLACK	GND	GND
3 ORANGE	100kΩ	R1
RED	+DC	+V
GREEN	−DC	−V
3 BLUE	1kΩ	R6

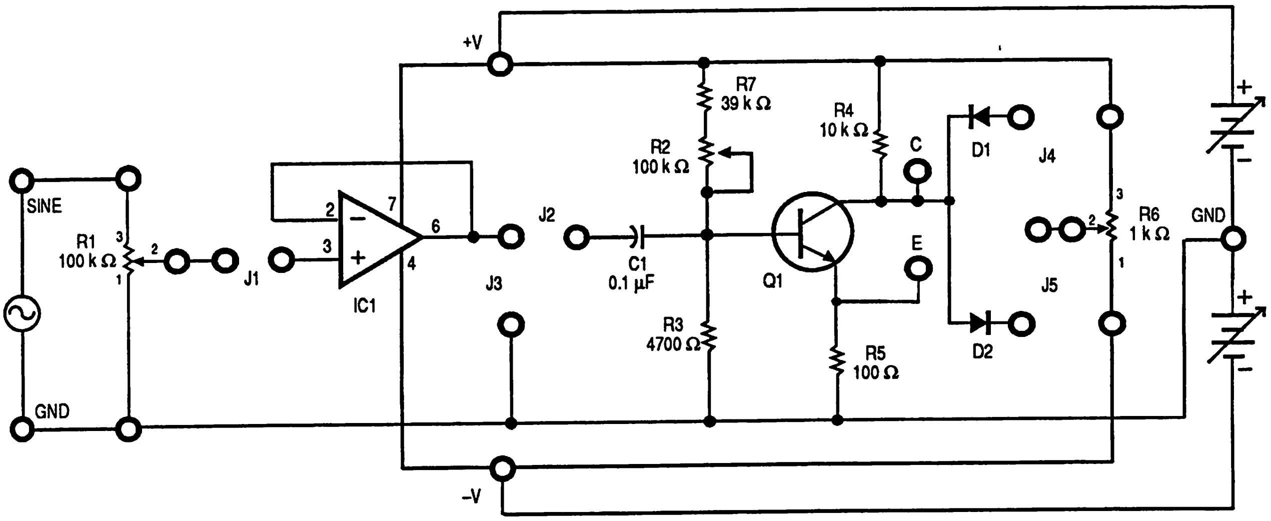


Figure E20-2
Experimental LED circuit.

3. Turn the Trainer on. Switch Board #3 ON and set the Trainer's positive and negative DC power supply controls fully clockwise. Center the Trainer's 1 kilohm and 100 kilohm controls, set the generator frequency control to 1 kHz and the generator range switch to 1× position. Switch Board #3 OFF.

4. Set your oscilloscope Y1 and Y2 channels to AC coupling, vertical selector switch to 1 volt/cm, time cm switch (horiz. select) to 0.2 ms, Y1 trigger select, and the AC coupling mode. Connect the Y1 scope probe to terminal 2 of the 100 kilohm control R1 (OSC1).

5. Switch Board #3 ON and adjust R1 for a 2-volt peak-to-peak scope presentation. Switch Board #3 OFF. Remove Y1 probe and install a white jumper wire at J1. This connects the 100 kilohm center terminal to pin 3 of the op amp. Connect the Y2 scope probe to pin 6 of the op amp (OSC2). Switch Board #3 ON. What is the amplitude of the signal at pin 6? ____________ . Is it in- or out-of-phase with the input signal? ____________ . Switch Board #3 OFF. Remove the Y2 scope probe from OSC2.

6. Now install a jumper wire at J3. This connects pin 6 of the op amp to ground. Switch Board #3 ON and carefully measure the signal at pin 3 of IC1 with the Y1 scope probe. Record the scope measurement below. Then switch the board off and remove the jumper at J3.

with pin 6 shorted to ground, pin 3 measures _____ volts (p-p)

Discussion

In this part of the experiment you adjusted the input signal from the generator through the 100 kilohm control to 2 volts peak-to-peak on the oscilloscope. Then you measured the output of the op amp and found it to be the same amplitude and in-phase with the input. Therefore the op amp is wired as a voltage follower. Next you shorted the output of the op amp while you monitored the input of the op amp and the waveform displayed on the scope should have remained at the 2 volt level. This is an example of the isolation (buffer) application of the op amp. The op amp isolated the input signal from the grounded output.

Procedure (Cont.)

7. Set your multimeter to measure DC voltage and connect it to the center terminal of the 1 kilohm control (R6). Switch Board #3 ON. Adjust R6 until the meter reads zero volts. Switch Board #3 OFF and install a white jumper wire at J4. Change the Y2 volts/cm switch on the scope to 5 volts/cm and DC coupling. Connect the Y2 scope probe to the collector (C) of transistor Q1. Switch Board #3 ON. Now rotate R6 fully clockwise and then fully counterclockwise. Watch the scope display while you are rotating R6. When finished, move the jumper wire from J4 to J5. Again rotate R6 while observing the scope's display. Remove the jumper at J5 and return R6 to its zero volts position using the meter.

8. With the scope still connected to the collector of Q1, adjust the bias network (100 kilohm control R2) for full scale scope deflection (approximately +10 volts DC). Then reverse your adjustment until the scope measures 5 volts DC. With your meter, measure the voltage at the emitter and the base of the transistor. Record the measurements below. Turn Board #3 OFF and read the following discussion.

collector voltage = +5 volts

emitter voltage = ______ volts

base voltage = ______ volts

Discussion

In step 7, you demonstrated a simple voltage divider circuit that is capable of supplying any voltage between a positive DC voltage and a negative DC voltage. This circuit will be used as a shunt (parallel) clipper later in the experiment.

In step 8, you tested the transistor circuit and by adjusting the base bias network you could cause the transistor to cut off or saturate. You left the circuit adjusted midway between saturation and cut off (5 volts) which is the linear gain range. Next, you measured the voltage at the emitter and base of the transistor and you should have measured approximately zero at the emitter and +0.7 at the base. Remember, that the drop across a silicon transistor's emitter base junction is about 0.7 volts when conducting. Since the transistor is conducting and the voltage is + the transistor must be an NPN type. Remember, forward bias the emitter and reverse bias the collector for proper transistor operation.

Procedure (Cont.)

9. Install the jumper wire at J2. This connects pin 6 of the op amp to capacitor C1. With the Y2 scope still connected to the collector of Q1, switch Board #3 ON. Observe the scope's waveform. The waveform should resemble a square wave.

10. Adjust the 100 kilohm control (R1) counterclockwise until the scope display is a sine wave. Using the scope, measure the amplitude of the scope waveform and record your measurement below.

    E_C = ______ volts (p-p)

11. Switch your ch. Y1 scope to 0.1 volts/cm and AC coupling. Move the Y1 scope probe to the base of the transistor and record the amplitude of the sine wave that is applied to the base below.

    E_B = ______ volts (p-p)

12. Switch your scope's Y2 setting to 0.1 V/cm and AC coupling. Move the Y2 scope probe to the emitter of the transistor and record the amplitude of the sine wave displayed.

    E_E = ______ volts (p-p)

13. Calculate the voltage gain when the circuit is used as a common emitter amplifier. Calculate the voltage gain when the circuit is used as a common collector amplifier.

common emitter gain = ______

common collector gain = ______

14. Recheck the collector, base, and emitter waveforms with the scope and complete the following statements.

The ______ and ____________ are in phase.

The ______ and ____________ are inverted.

15. Switch Board #3 OFF. Reset the scope's Y2 channel volts/cm switch to 2 volts and connect the Y2 scope probe to the transistor's collector. Remove the end of jumper J2 at the capacitor and connect it to the transistor's emitter at point E. Connect the Y1 probe to the top lead of R5 to observe the waveform at the emitter. Switch Board #3 ON and observe the collector waveform on the scope. Adjust R2 and R1 for a maximum amplitude sine wave with minimum distortion. Is the emitter waveform in- or out-of-phase with the collector? ____________ . Calculate the gain by dividing the peak-to-peak collector voltage by the peak-to-peak emitter voltage. ______ . Switch Board #3 OFF.

Discussion

In step 9, you applied the input signal to the base of the transistor and observed the output on the oscilloscope. The waveform should have resembled a square wave. This is because the transistor is driven into saturation and cut off. That indicates that the amplifier is functioning as an overdriven amplifier.

Next, you reduced the input amplitude until the transistor was neither saturated nor cut off. The amplifier is now operating in its linear range and the output sine wave peak-to-peak amplitude should be slightly less than 10 volts. Next you measured the base and emitter waveforms and calculated the gain of the amplifier.

In the common emitter configuration the input (base) was approximately 0.2 volts peak-to-peak and the gain was approximately 60. The amplitude of the waveform at the emitter was less than the base input, probably about 30 percent less.

A capacitor is used between the op amp's output and the base of the transistor. This prevents the op amp's DC output voltage from affecting the DC bias on the transistor.

Next you compared the phase of the base, emitter, and collector waveforms. You should have found the base and emitter to be in phase and the base and collector waveforms to be 180 degrees out of phase (inverted).

Then you moved the input signal from the base to the emitter. You should have noticed that the emitter and collector waveforms are in phase and the output is severely distorted (clipped) on the negative half of the waveform. This indicates that the transistor is saturating when the emitter goes negative (forward bias). After adjusting R1 and R2 you should have noticed that the gain is slightly higher. With the input signal being injected into the emitter, the circuit becomes a common-base amplifier.

Procedure (Cont.)

16. Remove the jumper wire from the emitter and reconnect it to the end of the capacitor (J2). The Y2 scope probe should still be connected to the collector. Adjust R1 and R2 for a sine wave of maximum amplitude and minimum distortion. Set R6 to its midway position. Reinstall the white jumper wire at J4. Switch Board #3 ON.

17. Rotate R6 slowly fully clockwise and then fully counterclockwise. Watch for clipping on the output waveform. Reset R6 to its midway position. Remove the jumper wire at J4 and install it at J5. Again rotate R6 slowly and watch for clipping on the output waveform. This completes the experiments. Switch Board #3 OFF and turn off your Trainer. Then read the following discussion.

Discussion

In steps 15 and 16, you used the control circuit (R6) tested earlier as a limiting control for the output of the amplifier. The diodes are used as shunt (parallel) clippers and they are biased by the variable 1 kilohm control. This circuit could be used to eliminate either the positive or negative portion of the waveform or simply to restrict the output in either direction. In a practical circuit the bias voltages would come from 2 separate supplies and then both diodes could be used in the circuit at the same time. This circuit is often used to limit a circuit feedline to a safe level. In other words, a method of providing protection to an expensive delicate load such as an expensive IC.

Summary

In this experiment, you combined an integrated solid state chip, a transistor, and diodes into an electronic circuit. You tested each section and then combined them into a combination circuit with a single input and output.

First, you adjusted an input signal from a generator through a 100 kilohm control to 2 volts peak-to-peak on your oscilloscope. Then you measured the output of the op amp and found it to be the same amplitude and in-phase with the input. Therefore the op amp is wired as a voltage follower. Next you shorted the output of the op amp to show the isolation or buffer ability of the op amp. In effect, the op amp shields the input signal from the grounded output.

Secondly, you demonstrated a simple voltage divider circuit. You found that a potentiometer between two opposite polarity DC power supplies can produce a variety of voltages between the positive DC voltage and the negative DC voltage, including zero.

Then you tested the transistor circuit. You found that by adjusting the base bias network you could cause the transistor to cut off or saturate. After adjusting the transistor midway between saturation and cut off, which is the linear gain range, you measured the voltage at the emitter and base of the transistor. You should have measured approximately zero at the emitter and +0.7 at the base. Remember, that the drop across a silicon transistor's emitter base junction is about 0.7 volts when conducting. Since the transistor is conducting and the voltage is + the transistor must be an NPN type. All this fits in with what you have previously learned— forward bias the emitter and reverse bias the collector for proper transistor operation.

After testing the transistor you connected the output of the IC to the input of the transistor. You observed a square wave at the output on the oscilloscope. This is because the transistor is driven into both saturation and cut off. That indicates that the amplifier is functioning as an overdriven amplifier.

By reducing the input amplitude, you placed the operation of the transistor in its linear region. Next you measured the base and emitter waveforms and calculated the gain of the amplifier. Comparing the phase of the base, emitter, and collector waveforms you found the base and emitter to be in phase and the base and collector waveforms to be 180 degrees out of phase (inverted).

Then you connected the input to the emitter of the transistor amplifier. This circuit then became a common-base configuration.

In the final part of the experiment, you used diodes as a limiting control for the output of the amplifier. The diodes were used as shunt (parallel) clippers and were biased by the variable 1 kilohm control. This circuit was used to eliminate either the positive or negative portion of the waveform or simply to restrict the output in either direction.

The circuit in this experiment is often used to limit a circuit feedline to a safe level. In other words, a method of providing protection to an expensive delicate load such as an expensive IC.

Unit Examinations

Unit 1 Examination

1. A typical atom within a pure semiconductor material will have how many electrons in its valence shell?

   A. 2
   B. 3
   C. 4
   D. 8

2. Components which are made from semiconductor materials are often called:

   A. high-voltage components.
   B. passive components.
   C. low-voltage components.
   D. solid-state components.

3. By using semiconductor materials it is possible to construct electronic components that:

   A. can withstand extremely high voltages.
   B. are small but not highly reliable.
   C. are suitable for use in portable or compact electronic equipment because they are small and consume less power.
   D. are highly reliable, are not sensitive to temperature changes and consume more power than tube.

4. The atoms within a pure semiconductor are held together:

   A. by covalent bonds.
   B. by their positive and negative charges.
   C. in a random manner.
   D. like the atoms within a conductor.

5. Intrinsic semiconductors can be made to perform as conductors or insulators by:

   A. subjecting them to high voltages.
   B. varying the temperature of the material to extreme limits.
   C. controlling the amount of doping.
   D. subjecting them to either a positive or a negative voltage.

6. The main reason for doping a semiconductor is to:

   A. make it physically stronger.
   B. make it insensitive to temperature changes.
   C. decrease its conductivity.
   D. increase its conductivity.

7. A hole behaves like a/an:

   A. positively charged particle.
   B. negatively charged particle.
   C. donor atom.
   D. acceptor atom.

8. Current flow in most semiconductor devices consists of:

   A. electrons only.
   B. holes only.
   C. electrons and holes.
   D. ions.

9. A pure semiconductor is converted to an N-type semiconductor when it is doped with:

   A. a pentavalent material.
   B. a trivalent material.
   C. either a pentavalent or a trivalent material.
   D. impurity atoms.

10. The number of holes and electrons flowing in a semiconductor material are equal when the material is:

    A. doped with a pentavalent impurity.
    B. doped with a trivalent impurity.
    C. doped with either a pentavalent or a trivalent impurity.
    D. in its intrinsic form.

11. The most popular and widely used semiconductor material is:

    A. germanium.
    B. silicon.
    C. carbon.
    D. arsenic.

12. The type of semiconductor material which utilizes electrons as majority carriers is:

    A. N-type.
    B. P-type.
    C. intrinsic.
    D. trivalent.

13. What sophisticated semiconductor component can replace an entire electronic circuit?

    A. diode
    B. transistor
    C. thyristor
    D. IC chip

14. In an electronic circuit, a semiconductor device:

    A. replaces discrete components like resistors and capacitors.
    B. controls the flow of current to produce a predetermined effect.
    C. can directly replace vacuum tubes.
    D. compensates for a variety of deficiencies.

15. Which of the following is **not** a benefit of semiconductor devices?

    A. lower cost
    B. less power consumption
    C. higher reliability
    D. higher operating voltages

16. Electrons and holes travel in the:

    A. same direction.
    B. toward the negative potential.
    C. toward the positive potential.
    D. in opposite directions.

17. Select the most correct statement from the list below.

    A. Electrons orbit around the protons.
    B. Protons orbit around the electrons.
    C. Electrons orbit around the nucleus of an atom.
    D. Protons and electrons are contained in the nucleus of an atom.

18. The valance band or shell of an atom is always:

    A. the band closest to the nucleus of the atom.
    B. the band furthest from the nucleus of the atom.
    C. the first shell that contains a full complement of electrons.
    D. the outer most shell if it has a full complement of electrons.

19. The atoms in semiconductor materials are arranged in a structure often referred to as a:

    A. crystal lattice.
    B. neutral atom.
    C. non-metallic element.
    D. diode.

20. The 3 general categories in which solid state components are usually classified are:

    A. resistors, transistors, and diodes.
    B. integrated circuits, diodes, and transistors.
    C. passive, active, and amplifying devices.
    D. trivalent, tetravalent, and pentavalent materials.

Unit 2 Examination

1. When a PN junction is formed, the area around the junction loses its majority carriers and is therefore referred to as the:

   A. vacuum region.
   B. barrier zone.
   C. depletion voltage.
   D. depletion region.

2. The positive and negative ions on each side of the PN junction create an internal voltage which is called the:

   A. barrier voltage.
   B. breakdown voltage.
   C. depletion region.
   D. depletion voltage.

3. When a PN junction diode is reverse-biased, the device will:

   A. conduct a relatively high forward current.
   B. conduct a small leakage current.
   C. conduct a high reverse current.
   D. not conduct until the external bias voltage is greater than 0.7 volts.

4. The majority carriers in a forward-biased PN junction diode are forced to:

   A. gather at the outer edges of the diode.
   B. move away from the junction and widen the depletion area.
   C. leave the diode and recombine within the battery.
   D. combine at the junction.

5. A diode's V-I characteristic curve shows how the diode's:

   A. forward current varies with temperature.
   B. barrier voltage varies with temperature.
   C. forward and reverse currents vary when the forward and reverse voltages are changed.
   D. depletion area varies with forward voltage.

6. The reverse voltage that causes the reverse current in a diode to suddenly increase is referred to as the diode's:

   A. reverse bias voltage.
   B. breakdown voltage.
   C. peak inverse voltage.
   D. forward saturation voltage.

7. The forward voltage across a conducting silicon diode will:

   A. be lower than the forward voltage across a germanium diode that is operating under similar conditions.
   B. be equal to the external bias voltage.
   C. have a typical value of 0.3 volts.
   D. be higher than the forward voltage across a germanium diode that is operating under similar conditions.

8. When a PN junction is formed by allowing a pellet of indium to fuse or melt into an N-type semiconductor crystal, the construction is referred to as the:

   A. alloyed method.
   B. grown method.
   C. diffusion method.
   D. depletion method.

9. The bar or rectangle portion of the diode symbol represents the:

   A. the input side of the diode.
   B. anode end of the diode.
   C. cathode end of the diode.
   D. type of material used to construct the diode.

10. When a diode is used to convert alternating current into direct current it is commonly referred to as a/an:

    A. alternator.
    B. rectifier.
    C. commutator.
    D. regulator.

11. The current flowing in the circuit shown below is:

    A. practically zero.
    B. 0.7 mA.
    C. 5.3 mA.
    D. 6 mA.

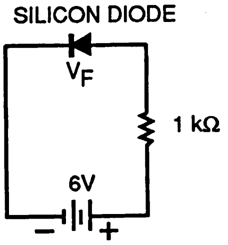


Figure 2-1

12. The voltage drop across the diode in the circuit above is:

    A. 0.3 volts.
    B. 0.7 volts.
    C. 5.3 volts.
    D. 6 volts.

13. The current flowing in the circuit shown below is:

    A. Practically zero.
    B. 0.1 mA.
    C. 3.9 mA.
    D. 4 mA.

14. The voltage across the diode is:

    A. 0.3 volts.
    B. 0.7 volts.
    C. 11.7 volts.
    D. 12 volts.

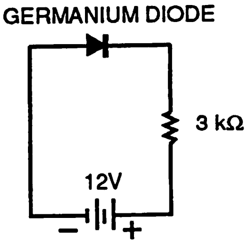


Figure 2-2

15. The most widely used method of constructing a semiconductor diode is by the:

A. alloyed method.
B. grown method.
C. diffused method.
D. hybrid method.

16. The instrument most widely used by bench technicians to test semiconductor diodes is a:

A. voltmeter.
B. ammeter.
C. oscilloscope.
D. ohmmeter.

17. Temperature variations have the greatest effect on which of the following diode characteristics?

A. forward voltage.
B. forward current.
C. leakage current.
D. PIV.

18. The term diode means:

A. rectifier.
B. 2 element device.
C. a silicon or germanium device.
D. 2 junction device.

19. When compared to a silicon diode the germanium diode has:

A. lower internal voltage drop.
B. higher gain capability.
C. a higher barrier voltage potential.
D. a wider depletion zone.

20. The knee of a diode's I-V curve refers to:

    A. the point where forward current starts to flow.
    B. the point where current ceases to flow.
    C. the point where reverse current starts to flow.
    D. the point where current increases rapidly.

Unit 3 Examination

1. When a zener diode is operating in its zener breakdown region, a large change in zener current will produce:

   A. a large change in zener voltage.
   B. a proportional change in zener voltage.
   C. a relatively small change in the diode's reverse voltage.
   D. absolutely no change in the diode's reverse voltage.

2. A zener diode's power dissipation rating is usually given for a specific:

   A. operating voltage.
   B. zener test current.
   C. zener impedance.
   D. operating temperature.

3. In general, a properly installed zener diode can dissipate more power if its axial leads are:

   A. shortened.
   B. curved.
   C. straight.
   D. lengthened.

4. The maximum reverse current that can flow through a zener diode without exceeding the diode's power dissipation rating is commonly designated as:

   A. I_{ZT}.
   B. I_{ZM}.
   C. I_{ZK}.
   D. I_Z.

5. The exact amount of zener voltage change that occurs over a specific temperature range can be determined by using the diodes:

   A. temperature compensation factor.
   B. zener impedance.
   C. derating factor.
   D. zener voltage temperature coefficient.

6. When a zener diode has an extremely low zener impedance, its:

   A. zener voltage varies only slightly with changes in zener current.
   B. zener voltage remains constant with changes in zener current.
   C. zener current varies only slightly while its zener voltage varies over a wide range.
   D. zener current remains constant while its zener voltage varies only a small amount.

7. A diode that has a zener voltage rating of 6.2 volts will usually have a:

   A. high zener knee impedance.
   B. high power dissipation rating.
   C. positive zener voltage temperature coefficient.
   D. negative zener voltage temperature coefficient.

8. A diode's specified zener voltage (V_Z) is that voltage which is dropped across the diode when the current through the device is at a specific level called the:

   A. maximum zener current.
   B. zener test current.
   C. minimum zener current.
   D. forward test current.

9. When used in a properly designed voltage regulator circuit, a zener diode is capable of maintaining a relatively constant output voltage:

   A. as long as the output load current remains constant.
   B. as long as the input voltage remains constant.
   C. when the input voltage or the output load current changes.
   D. when only the output load current changes.

10. If the series resistance required by a voltage regulator is calculated to be 215 ohms, it would be desirable to use a standard resistance value of:

    A. 150 ohms.
    B. 180 ohms.
    C. 220 ohms.
    D. 270 ohms.

11. The maximum current that a 15 volt, 1 watt zener diode can handle without damage is:

    A. 15 mA.
    B. 66 mA.
    C. 132 mA.
    D. 1 amp.

12. To bias a zener for proper operation as a regulator:

    A. the input voltage should be equal to the zener voltage.
    B. the load current should be less than the zener current.
    C. the anode should be positive with respect to the cathode.
    D. the cathode should be positive with respect to the anode.

13. A forward biased zener diode has a voltage drop equal to:

    A. 0.3 volts.
    B. 0.7 volts.
    C. V_Z.
    D. V_Z +0.7 volts.

14. In a zener regulator circuit, an increase in input voltage will cause:

A. an increase in zener current.
B. an increase in load current.
C. an increase in load voltage.
D. a decrease in zener current.

15. An increase in the zener regulator's load resistance will cause the zener current to:

A. decrease.
B. increase.
C. remain almost constant.
D. first decrease and then increase.

16. The zener diode is most commonly used as a:

A. series regulator.
B. shunt regulator.
C. power regulator.
D. current regulator.

17. The maximum current the zener diode in the circuit below must be able to handle is approximately:

A. 28 mA.
B. 90 mA.
C. 54 mA.
D. 62 mA.

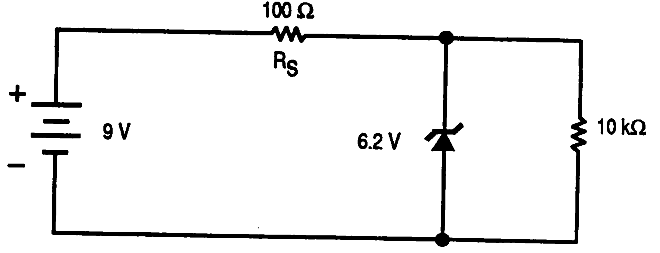


Figure 3-1

18. The voltage that a zener diode provides to the output load resistor is determined primarily by the:

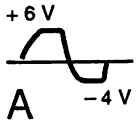
A. manufacturer.
B. input voltage.
C. output load current.
D. manufacturing process used.

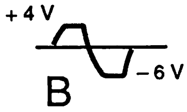
19. Shortening the zener diode's leads will:

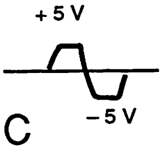
    A. decrease its current handling capability.
    B. increase its current handling capability.
    C. increase its power rating.
    D. decrease its power rating.

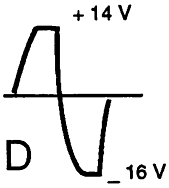
20. Select the correct output waveform for the circuit shown below.

    A.
    B.
    C.
    D.









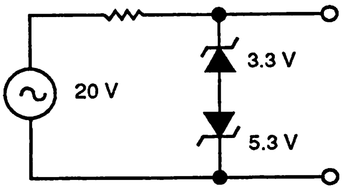


Figure 3-2

Unit 4 Examination

1. The tunnel diode has a PN junction that is:

   A. separated by an intrinsic layer.
   B. separated by a pure metal.
   C. lightly doped.
   D. heavily doped.

2. A tunnel diode is operating within its negative resistance region when its forward current:

   A. decreases as forward voltage increases.
   B. remains constant as forward voltage increases.
   C. increases as forward voltage increases.
   D. decreases as forward voltage decreases.

3. If a tunnel diode is to have a wide operating range within its negative resistance region it must have:

   A. high valley current.
   B. low peak current.
   C. low peak-to-valley current ratio.
   D. high peak-to-valley current ratio.

4. A varactor diode's internal capacitance increases as the diode's:

   A. leakage current increases.
   B. depletion region widens.
   C. reverse bias voltage decreases.
   D. reverse bias voltage increase.

5. Varactor diodes have a measurable Q because they have internal:

   A. capacitance only.
   B. capacitance and resistance.
   C. capacitance and inductance.
   D. variable capacitance.

6. The amount of power dissipated by a reverse-biased varactor diode is determined by the amount of:

   A. DC current flowing through the device.
   B. DC voltage developed across the device.
   C. both AC and DC currents flowing through the device.
   D. AC current flowing through the device.

7. The varactor diode becomes useless as a capacitor when it's:

   A. subjected to any reverse-bias voltage.
   B. subjected to a reverse-bias voltage that is just below its breakdown rating.
   C. operated in its forward conduction region.
   D. subjected to a varying reverse-bias voltage.

8. The PIN diode contains an N-section, a P-section and:

   A. a metal layer.
   B. an intrinsic layer.
   C. a region that is heavily doped.
   D. a region that is lightly doped.

9. The IMPATT diode is used to:

   A. provide a regulated output voltage.
   B. generate high power, low frequency signals.
   C. generate extremely high frequencies.
   D. provide rectification of low frequency signals.

10. The hot carrier diode utilizes a:

   A. semiconductor-to-metal junction.
   B. standard PN junction.
   C. metal-to-metal junction.
   D. PIN junction.

11. Which type of diode does not normally operate in the reverse biased condition?

    A. IMPATT
    B. tunnel
    C. zener
    D. varactor

12. Which type of diode is not normally used to generate high frequency or microwave signals?

    A. IMPATT
    B. tunnel
    C. zener
    D. Gunn

13. Operation of Gunn diodes depends on:

    A. the transferred electron effect.
    B. PN junction characteristics.
    C. avalanche breakdown.
    D. minority carriers.

14. The frequency of Gunn diode output pulses is determined by:

    A. the threshold voltage.
    B. domains.
    C. drift zone width.
    D. the external circuit.

15. Output pulse width from an IMPATT diode is determined by the:

    A. avalanche breakdown voltage.
    B. applied signal frequency.
    C. external circuit.
    D. drift zone width.

16. The term negative resistance refers to:

    A. resistance decreasing as voltage is increased.
    B. current decreasing as voltage is increasing.
    C. resistance increasing as current increases.
    D. current decreasing as resistance decreases.

17. The primary advantage of the Schottky diode is its:

    A. small size.
    B. low frequency of operation.
    C. speed of operation.
    D. high power dissipation rate.

18. Refer to the figure below. The Schottky diode is:

    A.
    B.
    C.
    D.

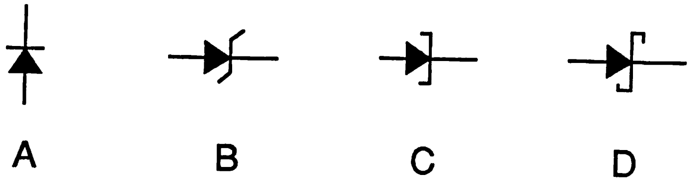


Figure 4-1

19. When reverse bias to a varactor diode is increased, internal capacitance:

    A. increases.
    B. decreases.
    C. is set by the manufacturer.
    D. is a function of the type of dielectric used.

20. The barrier voltage of a silicon Schottky diode is approximately:

    A. 0.3 volts.
    B. 0.6 volts.
    C. 0.7 volts.
    D. 1.4 volts.

Unit 5 Examination

1. Bipolar transistors may be classified as:

   A. NPN and PIN devices.
   B. NPN and PNP devices.
   C. NNP and PPN devices.
   D. N-type and P-type devices.

2. Bipolar transistors have:

   A. two PN junctions.
   B. one PN junction.
   C. three PN junctions.
   D. no PN junctions.

3. A bipolar transistor is constructed so that its base region is:

   A. very thick and heavily doped.
   B. very thin and heavily doped.
   C. very thick and lightly doped.
   D. very thin and lightly doped.

4. A transistor's emitter-base junction must always be:

   A. subjected to a high reverse current.
   B. biased the same as the collector-base junction.
   C. forward-biased.
   D. reverse-biased.

5. A transistor's collector-base junction must always be:

   A. subjected to a high forward current.
   B. reverse-biased.
   C. forward-biased.
   D. subjected to a low forward current.

6. A transistor's collector current is always:

   A. much lower than its emitter current.
   B. lower than its base current.
   C. slightly lower than its emitter current.
   D. higher than its emitter current.

7. When a transistor is connected in a common-base arrangement it is capable of providing:

   A. current amplification.
   B. current and voltage amplification.
   C. current and power amplification.
   D. voltage and power amplification.

8. The common-emitter circuit configuration provides:

   A. current, voltage, and power amplification.
   B. current and voltage amplification only.
   C. voltage and power amplification only.
   D. current and power amplification only.

9. A common-collector circuit arrangement may be used to:

   A. provide voltage amplification.
   B. provide current and voltage amplification.
   C. match a high impedance to a much lower impedance.
   D. match a low impedance to a high impedance.

10. When checking a good transistor with an ohmmeter, the device should exhibit a:

    A. small difference between forward-and-reverse resistance across each junction.
    B. large difference between forward-and-reverse resistance across each junction.
    C. high resistance in both directions across its emitter junction.
    D. low resistance in both directions across its collector junction.

11. When a transistor has a very low and almost equal forward and reverse resistance between its emitter and base leads, the device effectively has:

    A. a good emitter junction.
    B. a shorted collector junction.
    C. a shorted emitter junction.
    D. an open emitter junction.

12. When a transistor has an infinitely high forward and reverse resistance between its base and collector leads, the device effectively has:

    A. a good collector junction.
    B. an open collector junction.
    C. a shorted collector junction.
    D. an open emitter junction.

13. The basic transistor is defined as a/an:

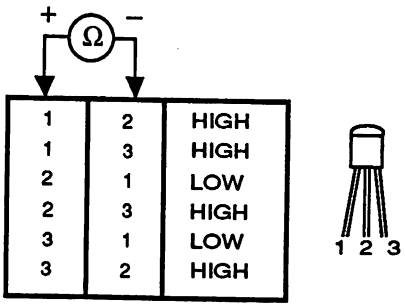
    A. NPN 3 element device used to control current flow.
    B. 2 junction device used to control current flow.
    C. 3 terminal device.
    D. 3 element device used to control current flow.

14. The arrow is always located in the:

    A. base lead and points to the emitter lead.
    B. emitter lead and points to N-type material.
    C. emitter lead and points to the base lead.
    D. collector lead and points to the N-type material.

15. The information in the chart below indicates that the transistor is a/an:

   A. NPN type and that lead 1 is the base lead.
   B. PNP type and that lead 1 is the base led.
   C. NPN type and that lead 2 is the base lead.
   D. PNP type and that lead 2 is the base lead.



1	2	HIGH
1	3	HIGH
2	1	LOW
2	3	HIGH
3	1	LOW
3	2	HIGH

Figure 5-1

16. By looking at a transistor you can determine:

   A. if it is an NPN or PNP type.
   B. if it is a bipolar or unipolar device.
   C. which lead is the collector lead.
   D. none of the above.

17. All of the current flowing in a bipolar transistor is equal to:

   A. I_E.
   B. I_C.
   C. I_B.
   D. $I_B + I_E$.

18. In a PNP bipolar transistor the majority current carriers are:

   A. electrons.
   B. holes.
   C. electron hole pairs.
   D. none of the above.

19. In circuit configurations or arrangements the term common is relative to:

    A. the input terminal.
    B. the output terminal.
    C. either the input or output terminals.
    D. both the input and output terminals.

20. Testing a transistor with an ohmmeter will verify that the transistor is:

    A. good.
    B. probably good.
    C. connected in the circuit properly.
    D. a planer type transistor.

Unit 6 Examination

1. A common-base transistor's collector characteristic curves are formed by plotting the relationship between I_C and V_{CB} for various values of:

   A. V_{CE}.
   B. I_B.
   C. I_E.
   D. V_{EB}.

2. A common-base transistor is operating within its saturation region when a small change in V_{CB} produces a large change in:

   A. V_{CE}.
   B. I_B.
   C. I_E.
   D. I_C.

3. A set of collector characteristic curves may be used to graphically determine a common-base transistor's:

   A. current gain.
   B. alpha cutoff frequency.
   C. I_{CEO} value.
   D. emitter breakdown voltage.

4. The current gain of a common-base transistor will always be:

   A. more than 1.
   B. slightly less than 1.
   C. exactly equal to 1.
   D. less than 0.90.

5. The current gain of a common-base transistor is often referred to as the transistor's:

   A. amplification factor.
   B. reverse current transfer ratio.
   C. alpha.
   D. beta.

6. The current gain of a common-base transistor will decrease if the input signal has a:

   A. sufficiently low frequency.
   B. sufficiently high frequency.
   C. very low amplitude.
   D. high degree of distortion.

7. In any transistor the quantity I_{CBO} exists because of:

   A. majority carriers in the transistor's emitter and base regions.
   B. majority carriers in the transistor's collector and base regions.
   C. minority carriers in the transistor's emitter and base regions.
   D. minority carriers in the transistor's collector and base regions.

8. The collector characteristic curves for a common-emitter transistor show the relationship between the transistor's:

   A. I_C, I_B, and V_{CE} values.
   B. I_C, I_B, and V_{CB} values.
   C. I_E, I_C, and V_{CB} values.
   D. I_E, I_B, and V_{CE} values.

9. The expression $(\Delta I_C/\Delta I_B)$ is used to determine a common-emitter transistor's:

   A. DC alpha.
   B. AC alpha.
   C. AC beta.
   D. DC beta.

10. The current gain of a common-emitter transistor:

    A. can never exceed 50.
    B. could be as high as 200.
    C. must be less than 1.
    D. is always more than 50.

11. A transistor that has an alpha of 0.97 will have a beta of approximately:

    A. 32.
    B. 320.
    C. 3.2.
    D. 64.

12. In any given transistor I_{CEO} is likely to be much higher than:

    A. any other circuit current.
    B. I_E.
    C. I_C.
    D. I_{CBO}.

13. The input resistance of a common-collector arrangement can be increased by using a:

    A. transistor with a lower alpha.
    B. transistor with a lower beta.
    C. higher value of load resistance.
    D. lower value of load resistance.

14. The output resistance of a common-collector arrangement is primarily controlled by:

    A. the transistor's beta and the internal resistance of the signal source.
    B. the output load resistance.
    C. the transistor's beta and the output load resistance.
    D. the internal resistance of the signal source and the load resistance.

15. A transistor dissipates power in the form of heat and most of the dissipation:

    A. occurs at the emitter junction.
    B. occurs at the collector junction.
    C. is spread evenly throughout the device.
    D. occurs within the emitter region.

16. Another expression for beta in a common emitter transistor circuit is:

    A. h_{fb}.
    B. f_T.
    C. h_{FE}.
    D. I_{CEO}.

17. Of the 3 basic circuit arrangements, the only configuration that inverts is the:

    A. common-base arrangement.
    B. common-collector arrangement.
    C. common-emitter arrangement.
    D. emitter-follower arrangement.

18. The only circuit arrangement that can amplify current, voltage, and power is the:

    A. common-emitter configuration.
    B. common-base configuration.
    C. common-collector configuration.
    D. emitter-follower arrangement.

19. The circuit configuration that has the lowest output impedance is the:

    A. common-emitter arrangement.
    B. common-base arrangement.
    C. common-collector arrangement.
    D. differential amplifier.

20. V_{BE} for the conducting silicon transistor in the circuit shown below

A. −0.3 volts.
B. +0.3 volts.
C. −0.7 volts.
D. +0.7 volts.

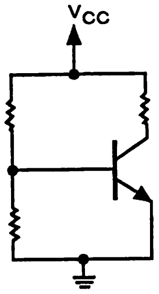


Figure 6-1

Unit 7 Examination

1. The junction FET has three leads which are referred to as the:

   A. emitter, base, and collector.
   B. emitter, gate, and collector.
   C. source, gate, and collector.
   D. source, gate, and drain.

2. The junction FET operates in the:

   A. enhancement mode.
   B. depletion mode.
   C. combined depletion-enhancement mode.
   D. depletion or enhancement mode.

3. When a junction FET's gate-to-source voltage is zero and the FET's drain-to-source voltage is greater than the FET's pinch-off voltage, the device will:

   A. conduct a substantial gate current.
   B. operate in the enhancement mode.
   C. conduct a substantial drain current.
   D. not conduct drain current.

4. The drain current produced by a properly biased N-channel junction FET will decrease when the FET's gate is:

   A. made more negative with respect to its source.
   B. made less negative with respect to its source.
   C. shorted to its source to reduce V_{GS} to zero.
   D. subjected to a potential which decreases the size of the depletion region.

5. The input resistance of a junction FET will remain extremely high as long as the FET's gate-to-channel junction is:

   A. biased so that the FET is operating in the enhancement mode.
   B. biased so that the gate current flows.
   C. forward-biased.
   D. reverse-biased.

6. The amplifying ability of an FET is expressed mathematically by the ratio:

   A. $A(I_D/V_{DS})$ with V_{GS} constant.
   B. $A(I_D/V_{GS})$ with V_{DS} constant.
   C. $A(I_G/AV_{GS})$ with V_{DS} constant.
   D. $A(V_{GS}/AI_D)$ with V_{DS} constant.

7. An insulated gate FET can be designed to operate in:

   A. the enhancement mode only.
   B. the depletion mode only.
   C. either the depletion or the enhancement mode.
   D. both the depletion and enhancement modes simultaneously.

8. Reversing the polarity of the gate-to-source voltage applied to a properly biased depletion mode insulated gate FET will:

   A. lower the FET's input resistance.
   B. produce a change in the FET's drain current.
   C. permanently damage the FET.
   D. cause the FET to conduct drain current in the opposite direction.

9. The enhancement mode insulated gate FET always conducts zero drain current when its:

   A. gate-to-source voltage is below a certain threshold value.
   B. drain-to-source voltage is very high.
   C. gate current is equal to zero.
   D. gate-to-source voltage is greater than a certain threshold value.

10. The relationship between an FET's gate-to-source voltage, drain current, and drain-to-source voltage can be determined by examining the FET's:

    A. source characteristic curves.
    B. gate characteristic curves.
    C. collector characteristic curves.
    D. drain characteristic curves.

11. FET's are often constructed in a symmetrical manner which makes it possible to interchange their:

    A. source and gate leads.
    B. source and drain leads.
    C. gate and drain leads.
    D. gate and substrate leads.

12. The lowest voltage gain is obtained when using an FET that is connected in a:

    A. common-collector circuit.
    B. common-source circuit.
    C. common-gate circuit.
    D. common-drain circuit.

13. The current that flows in a junction FET when $V_{GS} = 0$ is commonly identified as:

    A. I_{GS}.
    B. I_{DS}.
    C. I_{DSS}.
    D. I_S.

14. An IGFET is also referred to as a/an:

    A. MOSFET.
    B. NPN.
    C. JFET.
    D. PNP.

15. If V_S is greater than V_P, the drain current in a JFET will:

    A. be zero.
    B. vary little with changes in V_{DS}.
    C. be inversely proportional to gate voltage.
    D. be proportional to gate voltage.

16. The arrow in the FET symbol is always located in the:

    A. emitter lead.
    B. source lead.
    C. gate lead.
    D. drain lead.

17. When discussing FETs the term transconductance is equivalent to:

    A. 1/R.
    B. beta.
    C. alpha.
    D. E_{out}/E_{in}.

18. Transconductance (g_m) is measured in:

    A. ohms.
    B. volts.
    C. watts.
    D. mhos.

19. The picture below is the schematic symbol for a/an:

    A. P-channel enhancement mode FET.
    B. N-channel enhancement mode FET.
    C. P-channel depletion mode FET.
    D. N-channel depletion mode FET.

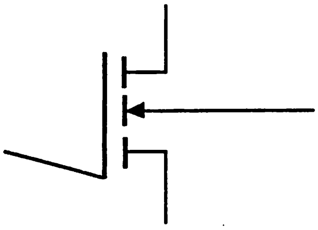


Figure 7-1

20. Select the correct statement from the list below.

    A. The depletion mode FET is considered to be a normally off device.
    B. The enhancement mode IGFET can only be turned on.
    C. The FET is more sensitive to electrostatic charges than the bipolar transistor.
    D. The FET uses both majority and minority current carriers.

Unit 8 Examination

1. An SCR will switch to the on state only when its:

   A. gate current is zero.
   B. forward breakover voltage is exceeded.
   C. reverse breakdown voltage is exceeded.
   D. gate current is below a certain threshold value.

2. An SCR will switch to the off state when its:

   A. gate current is reduced.
   B. gate current is increased.
   C. forward current is increased to a sufficiently high value.
   D. forward current drops below a level which will sustain conduction.

3. An SCR is normally biased so that it can be turned on by:

   A. momentarily increasing its forward voltage.
   B. increasing its reverse voltage.
   C. momentarily applying a gate current.
   D. momentarily decreasing its gate current.

4. When used in a half-wave phase control circuit an SCR is capable of varying the power applied to a load over a range that extends from zero to:

   A. 50 percent of the AC input power.
   B. 100 percent of the AC input power.
   C. 75 percent of the AC input power.
   D. 90 percent of the AC input power.

5. A TRIAC can control current flowing in either direction thro[illegible] its:

   A. MT_2 and gate terminals.
   B. MT_1 and MT_2 terminals.
   C. MT_1 and gate terminals.
   D. cathode and anode terminals.

6. The TRIAC can be turned on in either direction by a:

   A. positive gate voltage but not a negative gate voltage.
   B. gate current that flows out of the gate terminal only.
   C. gate current that flows into the gate terminal only.
   D. sufficiently high gate current that flows in either direction.

7. The TRIAC will switch to the off state when its main operating current (in either direction) drops below a specified value known as its:

   A. breakdown current.
   B. threshold current.
   C. holding current.
   D. leakage current.

8. When a TRIAC is used in a full-wave phase control circuit, it can vary the power applied to a load over a range that extends from zero to:

   A. 50 percent of the AC input power.
   B. 100 percent of the AC input power.
   C. 75 percent of the AC input power.
   D. 90 percent of the AC input power.

9. A device that is commonly used to trigger the TRIAC is referred to as a:

   A. bipolar transistor.
   B. triggering thyristor.
   C. SCR.
   D. DIAC.

10. The UJT turns on and exhibits a negative resistance between its ____________ and ____________ terminals after its V_P value is reached.

    A. emitter and base 1.
    B. emitter and base 2.
    C. base 1 and base 2.
    D. anode and cathode.

11. The UJT's negative resistance region is located between the:

    A. V_P and I_P points on its V-I curve.
    B. V_P and V_V points on its V-I curve.
    C. V_V and I_V points on its V-I curve.
    D. $+V_P$ and $-V_P$ points on its V-I curve.

12. The PUT has the same V-I characteristics as an ordinary UJT, however its V_P value can be varied by changing its:

    A. gate-to-cathode voltage.
    B. gate-to-anode voltage.
    C. anode-to-cathode voltage.
    D. anode-to-cathode current.

13. The device in the thyristor family that can control current equally in both directions is the:

    A. SCR.
    B. TRIAC.
    C. DIAC.
    D. PUT.

14. The thyristor device capable of handling the largest power surges is the:

    A. SCR.
    B. TRIAC.
    C. DIAC.
    D. UJT.

15. The thyristor device that is the equivalent of 2 paralleled SCRs is the:

    A. DIAC.
    B. TRIAC.
    C. UJT.
    D. PUT.

16. The thyristor that is used as a switching device and not as an amplifier is the:

    A. TRIAC.
    B. DIAC.
    C. UJT.
    D. all of the above.

17. The UJT has 3 leads and they are the:

    A. base, emitter, and collector.
    B. gate, source, and drain.
    C. emitter, base 1, and base 2.
    D. base, emitter 1, and emitter 2.

18. The thyristor device that can operate in the negative resistance region is the:

    A. UJT.
    B. SCR.
    C. DIAC.
    D. TRIAC.

19. The SCR, TRIAC, DIAC, UJT, PUT devices are shown respectively in the figure below by:

    A. A, B, C, D, and E
    B. A, C, D, B, and E.
    C. E, D, A, C, and B.
    D. A, E, D, C, and B.

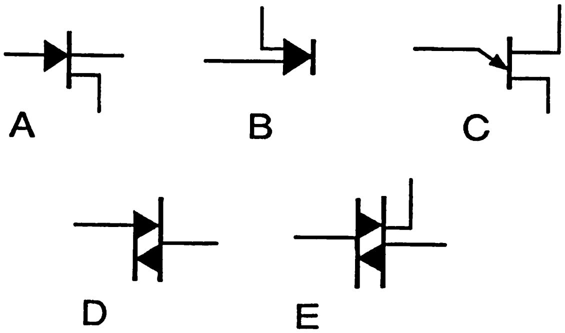


Figure 8-1

20. The thyristor that has its leads referred to as the gate, cathode, and anode is the:

    A. SCR only.
    B. DIAC only.
    C. TRIAC only.
    D. both A and B above.

Unit 9 Examination

1. The four components that are most commonly manufactured in IC's are.

   A. diodes, resistors, inductors, and capacitors.
   B. diodes, transistors, resistors, and inductors.
   C. diodes, transistors, resistors, and capacitors.
   D. transistors, resistors, inductors, and capacitors.

2. When compared to a discrete component circuit, the IC is:

   A. smaller, more reliable, and often less expensive.
   B. smaller, less reliable, and less expensive.
   C. smaller, more reliable, and generally more expensive.
   D. larger, more reliable, and less expensive.

3. The four basic types of integrated circuits are the:

   A. silicon, germanium, P-type, and N-type IC's.
   B. monolithic IC's, bipolar IC's, MOS IC's, and unipolar IC's.
   C. monolithic IC's, thin-film circuits, thick-film circuits, and hybrid circuits.
   D. monolithic, film-type, hybrid, and bipolar IC's.

4. Many monolithic IC's are simultaneously formed on a:

   A. glass substrate.
   B. ceramic substrate.
   C. circular ceramic wafer.
   D. circular semiconductor wafer.

5. Monolithic IC's may be formed by utilizing the construction techniques associated with bipolar transistors or field effect transistors and are usually classified as:

   A. bipolar IC's or MOS IC's.
   B. bipolar IC's or FET IC's.
   C. bipolar IC's or unipolar IC's.
   D. MOS IC's or FET IC's.

6. If a monolithic IC has only 20 components, it would be classified as a/an:

   A. LSI circuit.
   B. MSI circuit.
   C. SSI circuit.
   D. MOS circuit.

7. Integrated circuits that are formed by depositing layers of metals and oxides on insulating substrates by using evaporation or sputtering techniques, are referred to as:

   A. MOS circuits.
   B. thin-film circuits.
   C. thick-film circuits.
   D. hybrid circuits

8. When silk-screening techniques are used to form components and conductors on an insulating substrate, the resulting circuit is referred to as a/an:

   A. MOS circuit.
   B. bipolar circuit.
   C. thin-film circuit.
   D. thick-film circuit.

9. Monolithic IC's, thin-film and thick-film circuits, and also discrete components can be combined in various arrangements to produce a/an:

   A. bipolar IC.
   B. hybrid circuit.
   C. MOS circuit.
   D. LSI circuit.

10. The DIP is a popular type of:

    A. monolithic IC package.
    B. hybrid IC package.
    C. thick-film IC package.
    D. transistor package that is used with IC's.

11. Digital IC's are basically switching circuits which respond to:

    A. a continuously changing DC voltage.
    B. only zero and +3 volt levels.
    C. high and low logic levels.
    D. voltages that are between zero and +3 volts.

12. Two linear ICs that are commonly used are the:

    A. TTL NAND gate and CMOS NOR gate.
    B. operational amplifier and TTL NAND gate.
    C. operational amplifier and CMOS NOR gate.
    D. operational amplifier and voltage regulator.

13. Most ICs are considered to be:

    A. high powered devices.
    B. low powered devices.
    C. amplifying devices.
    D. high frequency devices.

14. The component hardest to manufacture in IC form and therefore the least used is the:

    A. capacitor.
    B. inductor.
    C. resistor.
    D. transistor.

15. When discussing the manufacture of solid state components the term yield refers to:

    A. number of chips on a wafer.
    B. number of good chips on a wafer.
    C. % of good chips on a wafer.
    D. % of bad chips on a wafer.

16. Select the correct statement concerning the manufacture of resistors in ICs.

    A. The higher the resistor value the less space required.
    B. Resistors with a 1% tolerance are easily manufactured.
    C. Resistor ratios with a tolerance of 1% are possible.
    D. Increasing the width of the resistor increases its resistance.

17. The basic logic gates are the:

    A. OR, AND, and NOT gates.
    B. NOR, NAND, and NOT gates.
    C. OR, NOR, and NAND gates.
    D. AND, NAND, and OR gates.

18. CMOS technology combines:

    A. NPN and PNP transistors into a complementary pair.
    B. N-MOS and P-MOS devices into a complementary pair.
    C. N-type and P-type material into a single device.
    D. discrete components into complementary pairs.

19. Select the correct statement concerning CMOS devices:

    A. CMOS devices consume less power than MOS devices.
    B. CMOS devices consume more power than MOS devices.
    C. CMOS devices have a shorter propagation delay than MOS devices.
    D. CMOS devices operate with higher currents than TTL devices.

20. The basic operational amplifier contains:

    A. current, power, and voltage amplifiers.
    B. differential, voltage, and output amplifiers.
    C. a complementary pair of amplifiers.
    D. a high impedance output amplifier.

Unit 10 Examination

1. Light is commonly measured by the:

   A. photometric system.
   B. radiometric system.
   C. both the radiometric and photometric systems.
   D. isometric system.

2. The photometric system is used to measure:

   A. visible light only.
   B. infrared light only.
   C. both visible and infrared light.
   D. the entire light spectrum.

3. Light is thought to consist of many tiny particles or bundles of energy called:

   A. neutrons.
   B. cosmic particles.
   C. protons.
   D. photons.

4. The resistance of a photoconductive cell will be extremely high when:

   A. it is exposed to a high intensity light.
   B. no light strikes its surface.
   C. it is reverse-biased.
   D. it is forward-biased.

5. The photovoltaic cell responds to changes in light intensity by:

   A. varying its transconductance.
   B. changing its conductivity.
   C. changing its resistance.
   D. generating an output voltage.

6. The photodiode may be used in the:

   A. photoconductive or photovoltaic mode.
   B. photovoltaic mode only.
   C. transconductive mode.
   D. photoconductive mode only.

7. When we compare photodiodes and phototransistors we find that phototransistors have a:

   A. higher output current and a faster response.
   B. lower output current and a faster response.
   C. higher output current but a slower response.
   D. lower output current and a slower response.

8. The LED emits light when the holes and electrons near its junction:

   A. separate.
   B. recombine.
   C. are forced to flow away from the junction.
   D. are forced to flow toward the junction without recombining.

9. Under normal operating conditions the forward voltage across an LED would most likely be between:

   A. 7 and 10 volts.
   B. 3 and 5 volts.
   C. 1 and 2 volts.
   D. 0 and 1 volt.

10. When we compare the LED with an incandescent lamp we find that the LED has a:

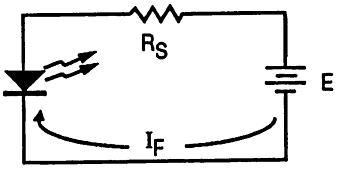
    A. slower response and produces less light.
    B. faster response and produces more light.
    C. slower response but produces more light.
    D. faster response but produces less light.

11. When an LED and phototransistor are mounted in the same package so that they are connected by a light beam which can transmit electrical signals, the device formed is known as:

A. an optical coupler.
B. an optical limit switch.
C. a photo-darlington circuit.
D. an LED display.

12. If an LED is connected as shown in the figure below and E equals 12 volts while I_F must equal 20 milliamperes, the required value of R_S would be (assume the diode voltage drop to be 1.6 volts):

A. 595 ohms.
B. 1040 ohms.
C. 520 ohms.
D. 515 ohms.



13. An advantage of LCDs over LED displays is that the LCD:

A. emits infrared light.
B. has lower power requirements.
C. emits visible light.
D. requires an external light source.

14. Application of an electric field to a liquid crystal causes the crystal to:

A. change its optical characteristics.
B. emit visible light.
C. become transparent.
D. emit infrared light.

15. The visible light spectrum is located between:

A. ultraviolet and x-ray spectrums
B. infrared and ultraviolet spectrums
C. infrared and radio wave spectrums
D. audio and radio wave spectrums

16. In optoelectronics the term luminance is a measure of:

A. light intensity.
B. light output.
C. light input.
D. steradians.

17. The Greek letter Lambda represents a measurement of:

A. light intensity.
B. frequency.
C. wave length.
D. radiance.

18. The schematic symbol below represents a/an:

A. photodiode.
B. LED.
C. photocell.
D. darlinton diode.

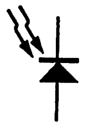


Figure 10-1

19. The efficiency of an LED is approximately:

A. 10%.
B. 40%
C. 60%.
D. 80%.

20. The term critical angle is normally associated with:

A. photodiodes.
B. LCDs.
C. LEDs.
D. optical couplers.